Naval Research Laboratory

Washington, DC 20375-5320

NRL/MR/6120--00-8483

Conductivity and Charging Tendency of JP-8 + 100 Jet Fuel

J.T. LEONARD

Geo-Centers, Inc.
Newton, MA

D.R. HARDY

Materials Chemistry Branch
Chemistry Division

September 18, 2000

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave Blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 18, 2000	Final

4. TITLE AND SUBTITLE

Conductivity and Charging Tendency of JP-8 + 100 Jet Fuel

5. FUNDING NUMBERS

6. AUTHOR(S)

J.T. Leonard* and D.R. Hardy

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/6120--00-8483

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Department of the Air Force
Wright Laboratory
AeroPropulsion and Power Directorate
Wright-Patterson Air Force Base, OH 45433-7103

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

*Geo-Centers, Inc.
Newton, MA 02459

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

The effects of the Betz Thermal Stability Additive, 8Q492, and the Octel Static Dissipater Additive, Stadis 450, on the electrical conductivity and electrostatic charging tendency of Jet A fuels were examined using a variety of filter media. It was found that the Betz additive, at a concentration of 256 mg/1, increased the conductivity of most fuels to above 100 pS/m and of 15% of the fuels to above 150 pS/m, which is the lower specification limit for JP-8 fuels. The Betz additive increased the charging tendency to very high levels on only two media, namely, the Type 10 reference filter and a coalescer medium. Charging on all other media including both the non-conductive and conductive reticulated foams was quite low.

Fuels containing Stadis 450 exhibited high charging on most coalescer media, particularly fiberglass and felt, and on the media paper and superabsorbent and absorbent media from the monitor cartridge. They also gave high charging on both the conductive and nonconductive foams, but not on the separator media or on the Type 10 reference filter.

14. SUBJECT TERMS		15. NUMBER OF PAGES
Jet fuel	Electrical conductivity	53
JP-8		16. PRICE CODE
Electrostatic charging		

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

CONDUCTIVITY AND CHARGING TENDENCY OF JP-8+ 100 JET FUEL

INTRODUCTION

The Air Force has recently developed a new additive package for JP-8 to produce "JP-8 + 100" jet fuel. In addition to improving the thermal stability of JP-8 fuel, the new additives also increase the electrical conductivity of the fuel. Since additives which increase the conductivity of fuel also increase its electrostatic charging tendency, this development has prompted the following questions:

1) Is the electrical conductivity of JP-8 +100 sufficiently high to obviate the need for the current static dissipater additive (SDA)?

2) Are there any unusual electrostatic charging characteristics associated with JP-8 +100 fuels?

The objective of this study is to provide answers to the questions above.

EXPERIMENTAL PROCEDURE

Forty-eight samples of Jet A fuels were provided by the Air Force Research Laboratory. Unless otherwise indicated, all of these samples contained:

1) A Corrosion Inhibitor (CI), Betz 8QM21, at 15 mg/l and

2) A Fuel System Icing Inhibitor (FSII), Diethyleneglycol monomethyl ether, at 0.1 vol. %.

Most of the samples also contained the Betz Thermal Stability Additive 8Q492 at a concentration of 256 mg/l. However, the Betz additive was omitted from certain samples for a baseline comparison. The Octel Static Dissipater Additive, Stadis 450 Enhanced, was used at a concentration of 1 ppm unless otherwise indicated.

The electrical conductivity of the fuel samples was measured using an Emcee Electronics, Inc. Precision Conductivity Meter, Model 1154 and the ASTM procedure (1). The charging tendency was determined using the EXXON Mini-Static Test Apparatus and Procedure (2). For the first phase of testing, Type 10 separator paper was used in the Mini-Static apparatus (Fig. 1). Type 10 paper was chosen because it was used previously in the CRC survey of fuels taken from commercial airports and military bases in the continental United States and Hawaii (3). A total of 410 samples, representing 338 commercial Jet A and Jet A-1 fuels, 54 JP-4 and 18 JP-5 fuels, were included in that survey. In addition, Type 10 paper was used to evaluate the charging tendency of a wide range of organic compounds, fuel additives and contaminants in a

Manuscript approved August 3,

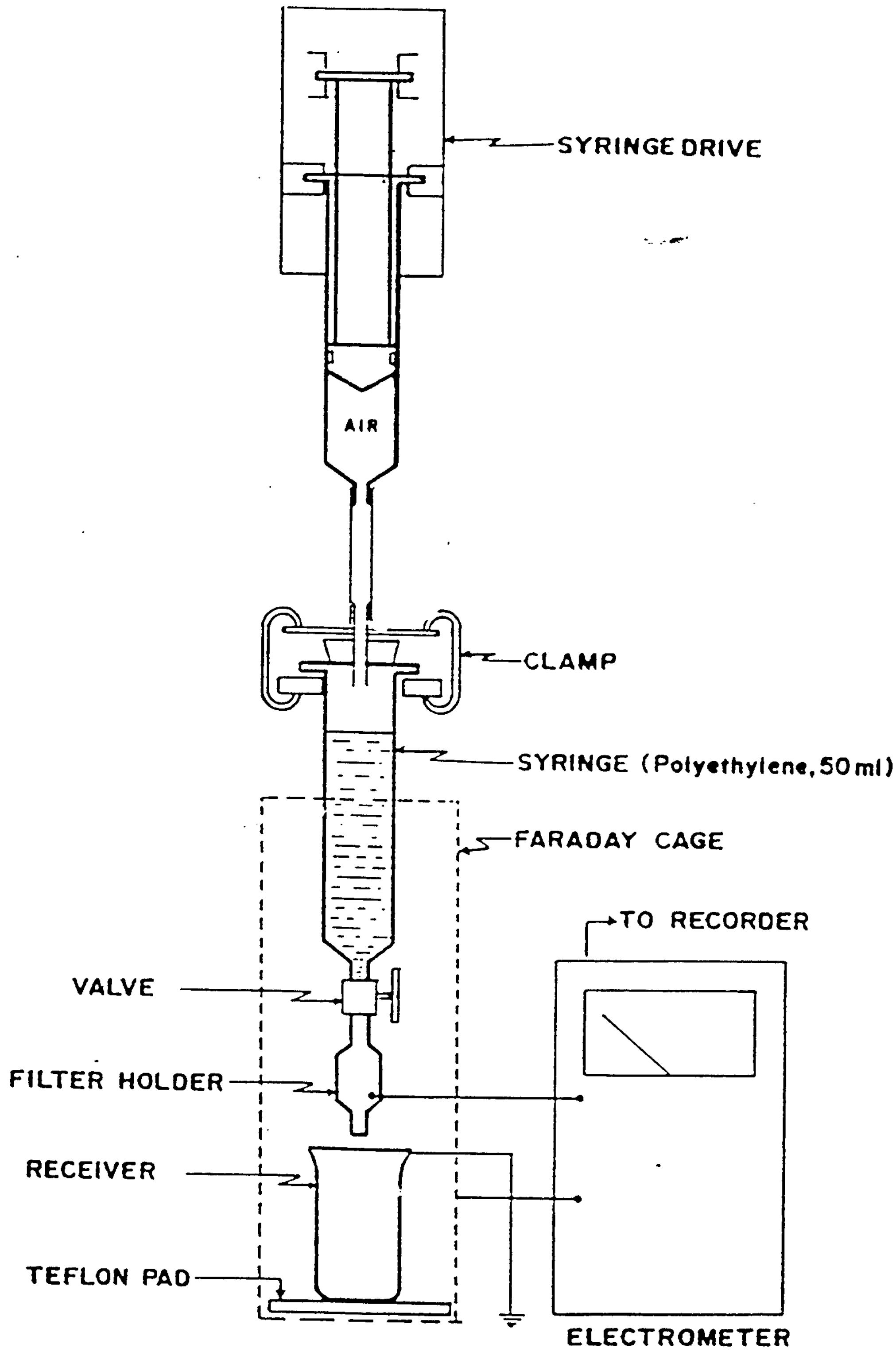


Fig. 1-EXXON Mini-Static Tester

later study (4). Hence, there is an abundance of data available on fuel charging with this particular paper.

Following the initial fuel conductivity and charging tendency measurements, the fuel samples were doped with 1 ppm Stadis 450 Enhanced (the currently approved static dissipater additive for JP-8 fuels) and the conductivity and charging tendency of the treated samples were measured.

In the second phase of the study, the charging tendencies of the highest charging JP-8 + 100 fuels were measured using a variety of filter media in place of the Type 10 paper in the EXXON Mini-Static Test Apparatus. The filter media were supplied by three manufacturers, namely: Facet International, Pall Corporation and Velcon Filters. The filters were representative of the media used in coalescers, separators and monitor cartridges. In addition, an experimental coalescer material was also tested. The filters were cut to fit the filter holder on the Mini-Static Test Apparatus using a 1.3 cm arch leather punch.

Finally, the charging tendencies of fuels containing the Betz Thermal Stability Additive were compared with the charging tendencies of the same fuels containing Stadis 450 using reticulated foam as the charging medium. For these tests, the filter holder was enlarged to accommodate a cylindrical section of foam (1.3 cm in diameter, 7.5 cm long), as was done in a previous study of reticulated foams (5).

RESULTS AND DISCUSSION

Typical filter current curves as obtained from the EXXON Mini-Static Tester are shown in Fig. 2. The vast majority of fuel samples produced curves like this after one or two passes through the filter. However, a few samples showed progressively increasing or decreasing filter currents and hence, could not be adequately measured by this technique. The filter currents were divided by the volumetric flow rate to express fuel charging tendency in microcoulombs per cubic meter ($\mu C/m^3$).

Conductivity of Fuels as Received

The conductivities of the fuel samples which did not contain the Betz additive are shown in Table 1 and in Fig. 3. Conductivity is expressed as picosiemens per meter (pS/m).

As indicated in Table 1, the conductivity of the neat fuel (Sample 1) was quite low (0.15 pS/m), but comparable to the lowest value (0.09 pS/m) found in a survey of Jet A fuels in 1975 (3). The addition of a Fuel System Icing Inhibitor (FSII) and Corrosion Inhibitor (CI) to this fuel (Sample 2) increased the conductivity only slightly (to 0.22 pS/m).

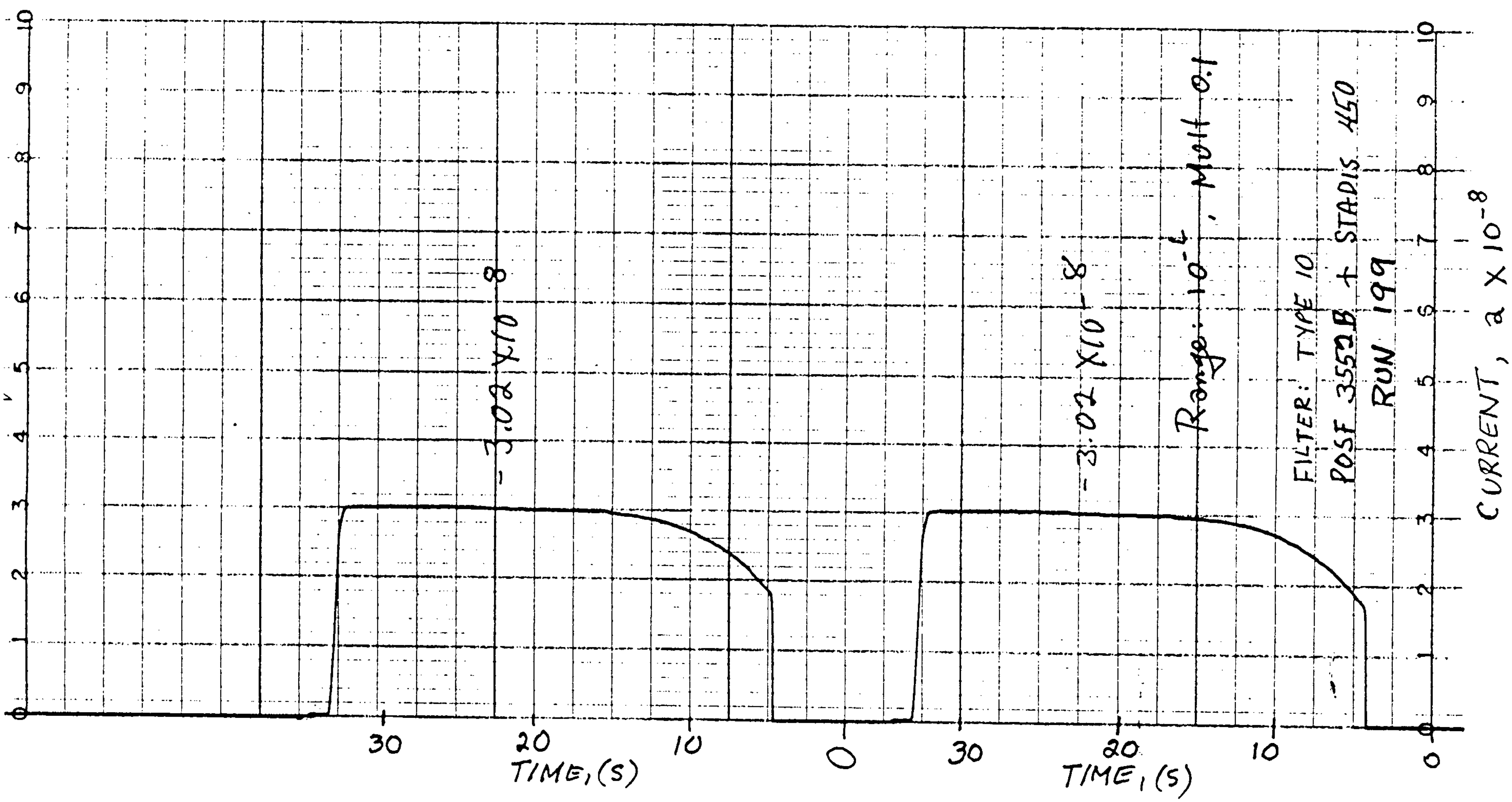


Fig. 2-Typical Filter Current Curves for Two Successive Passes of Fuel Sample Through a Type 10 Filter

Fig. 3- Conductivity of Fuels Not Containing Betz Additive

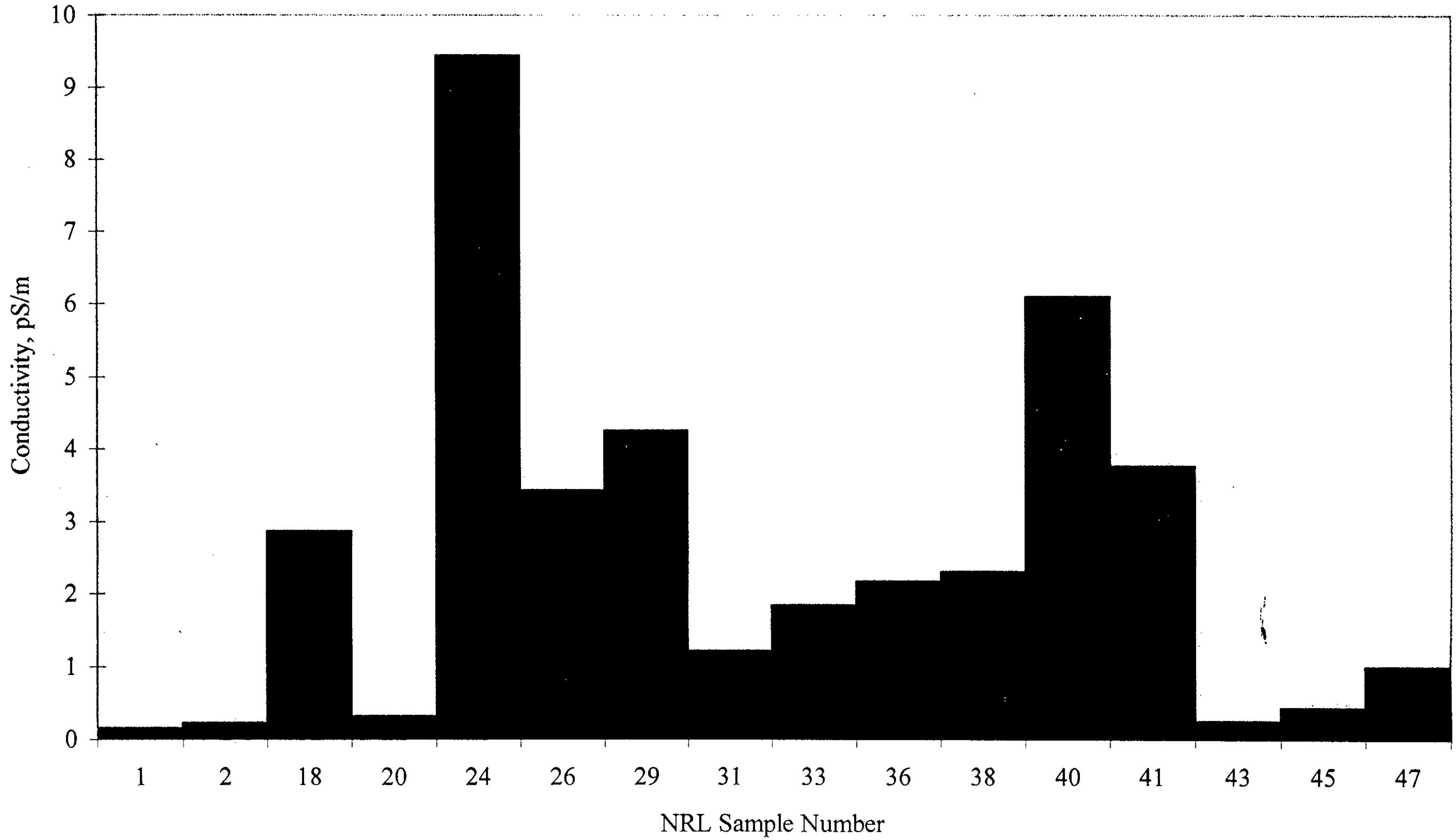


Table 1 – Conductivity and Charging Tendency of Fuel Samples Not Containing Betz Additive (Filter: Type 10 Paper)

NRL Sample No.	AF POSF No.	Conductivity, pS/m	Charge Density, μC/m^3
A. Samples in Normal Jet A Conductivity Range			
1	3428 (Neat)*	0.15	28
2	3428	0.22	480
18	3551A	2.86	1,120
20	3552A	0.31	231
24	3554A	9.44	1,080
26	3555A	3.43	1,890
29		4.25	392
31	3627B	1.22	397
33	3633B	1.84	171
36	3638B	2.17	634
38	3639B	2.30	528
40	3640B	6.10	488
41	3593A	3.76	702
43	3601A	0.25	131
45	3602A	0.43	519
47	3603A	1.00	610
B. High Conductivity Samples			
16	3550A	79**	>180
22	3553A	322**	5,950

* This sample did not contain FSII or CI

** High conductivity indicates that sample may have contained Stadis 450

With the exception of two Samples (Samples 16 and 22), which apparently contained a static dissipater additive, the conductivities of all of the other samples were within the "normal range" for Jet A fuel not containing the Betz additive, i.e., below 10 pS/m. (In the 1975 survey (3), 93% of the Jet A and Jet A-1 fuels had conductivities below 10 pS/m.) By contrast, the conductivities of all of the samples containing the Betz additive (Table 2 and Fig. 4) were over 50 pS/m, which is the specification lower limit for Jet A fuels (6). Thirteen had conductivities above 150 pS/m, the specification lower limit for JP-8 fuels (7). Eight of the samples in Table 2, namely, Samples 8, 10, 12, 13, 14, 15, 17 and 23, had such high conductivities as to suggest that they contained both Betz and Stadis additives.

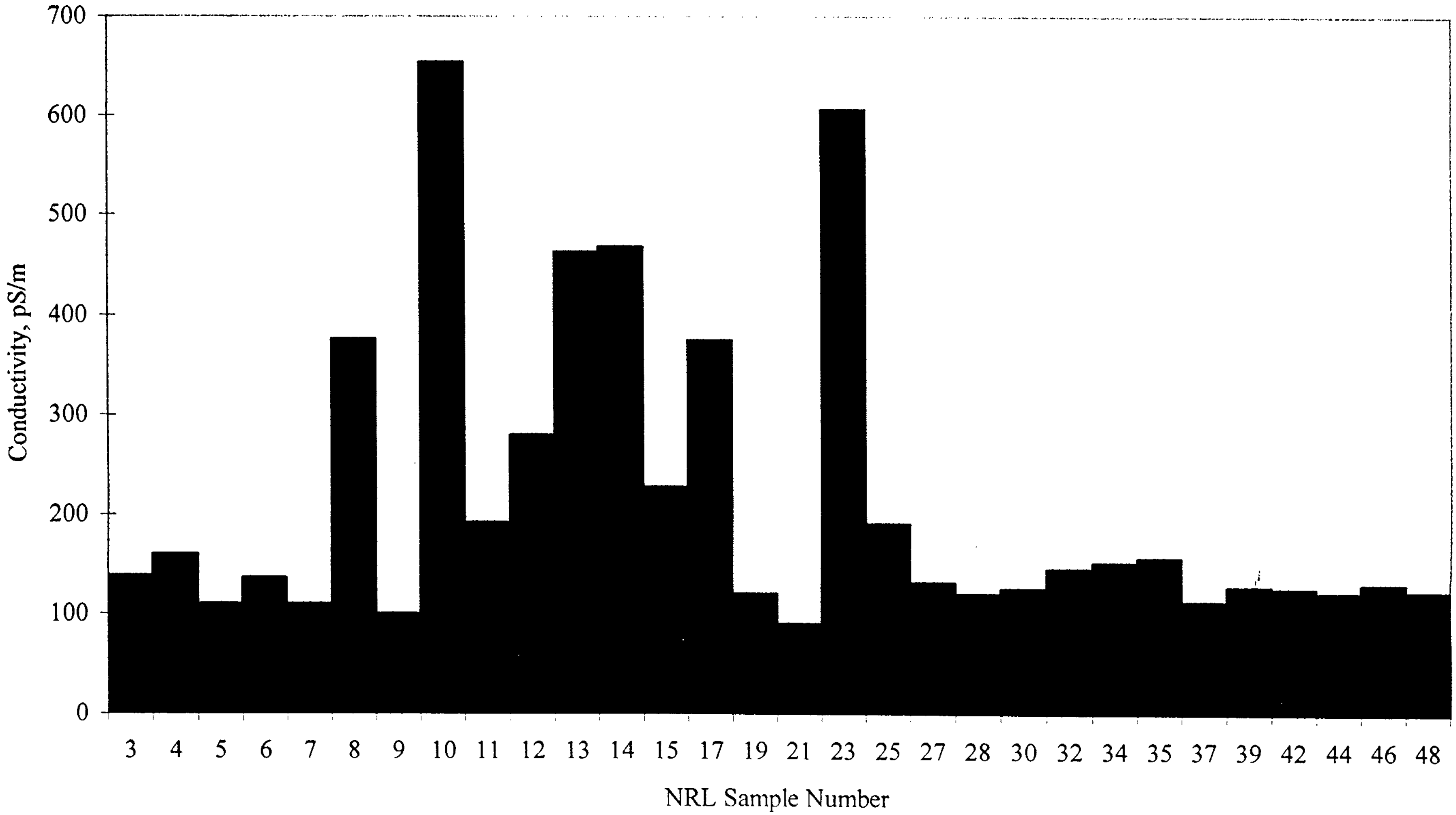
Table 2 – Conductivity and Charging Tendency of Fuel Samples Containing Betz Additive (Filter: Type 10 Paper)

NRL Sample No.	AF POSF No.	Conductivity, pS/m	Charge Density, μC/m³
A. Samples in Normal Conductivity Range for Betz Additive			
3	2827	138	11,500
4	2926	160	15,300
5	3055	110	14,500
6	3119	136	14,400
7	3166	110	13,600
9	3084	100	15,500
11	3476	192	23,900
19	3551B	121	3,210
21	3552B	90.5	7,810
25	3554B	191	2,490
27	3555B	132	1,452
28	3166**	121	10,980
30	3627A	126	7,110
32	3633A	146	3,360
34	3638	152	9,520
35	3638A	157	5,490
37	3639A	113	3,730
39	3640A	128	12,400
42	3593B	126	4,720
44	3601B	122	9,060
46	3602B	130	12,200
48	3603B	123	5,190
B. High Conductivity Samples			
8	3219	376*	17,700
10	3475	654*	19,300
12	3477	280*	26,100
13	3478	463*	26,000
14	3479	468*	22,000
15	3480	228*	22,600
17	3550B	375*	12,000
23	3553B	606*	13,800

* High conductivity indicates that sample may have contained Stadis 450, although it was not labeled as such

** Second sample

Fig. 4- Conductivty of All Fuels Containing the Betz Additive



The effect of the Betz additive on the conductivities of "normal" Jet A fuels (i.e. fuels having a conductivity <10 pS/m) is seen more clearly in Table 3. This table lists only those samples which were received with and without the Betz additive. For these fuels, the Betz additive increased the conductivity an average of 129 pS/m. All but one sample (92%) had conductivities above 100 pS/m, but only 2 out of 13 samples (15%) were above 150 pS/m.

Table 3 – Effect of Betz Additive on Conductivity and Charging Tendency of "Normal" Jet A Fuels (Filter: Type 10 Paper)

		Conductivity, pS/m			Charge Density, μC/m³		
NRL* Sample No.	AF* POSF No.	No Betz	With Betz	Δ	No Betz	With Betz	Δ
18 &19	3551A&B	2.86	121	+118	1,120	3,210	+2,090
20 & 21	3552A&B	0.31	90.5	+90.2	231	7,810	+7,579
24 & 25	3554A&B	9.44	191	+182	1,080	2,490	+1,410
26 & 27	3555A&B	3.43	132	+129	1,890	1,450	-440
30 & 31	3627A&B	1.22	126	+125	397	7,110	+6,713
32 & 33	3633A&B	1.84	146	+144	171	3,360	+3,189
35 & 36	3638A&B	2.17	157	+155	634	5,490	+4,856
37 & 38	3639A&B	2.30	113	+111	528	3,730	+3,203
39 & 40	3640A&B	6.10	128	+122	488	12,400	+11,912
41 & 42	3593A&B	3.76	126	+122	702	4,720	+4,018
43 & 44	3601A&B	0.25	122	+122	131	9,060	+9,029
45 & 46	3602A&B	0.43	130	+130	519	12,200	+12,070
47 & 48	3603A&B	1.00	123	+123	610	5,190	+4,580

* The dual sample numbers refer to the same sample, before and after the addition of the Betz additive

Although fuels vary in their response to the Betz additive as shown in Table 3, for a single fuel, the conductivity increases fairly linearly with concentration of Betz additive (Fig. 5).

In a previous study (4), it was found that the conductivities of Jet A fuels varied widely in response to corrosion inhibitors and other fuel additives when the fuels were doped at 100 and 1000 ppm levels. For example, all of the corrosion inhibitors increased the conductivity of Jet A fuel to some degree, but the most active corrosion inhibitor, Na-Sul LP, increased the conductivity of a Jet A fuel from 0.102 to 414 pS/m when used at the 1000 ppm level (Fig. 6). The thermal stability additive used in that study (JFA-5) had only a slight effect on fuel conductivity, raising it from 0.102 to 6.19 pS/m at the 1000 ppm level.

Charging of Fuels on Type 10 Reference Filter

The charging tendencies for the samples that didn't contain the Betz additive were generally low (Table 1 and Fig. 7), but within the range found for Jet A samples in the 1975

Fig. 5- Effect of Betz Additive on Conductivity of Jet A Fuel (NRL Sample No. 34)

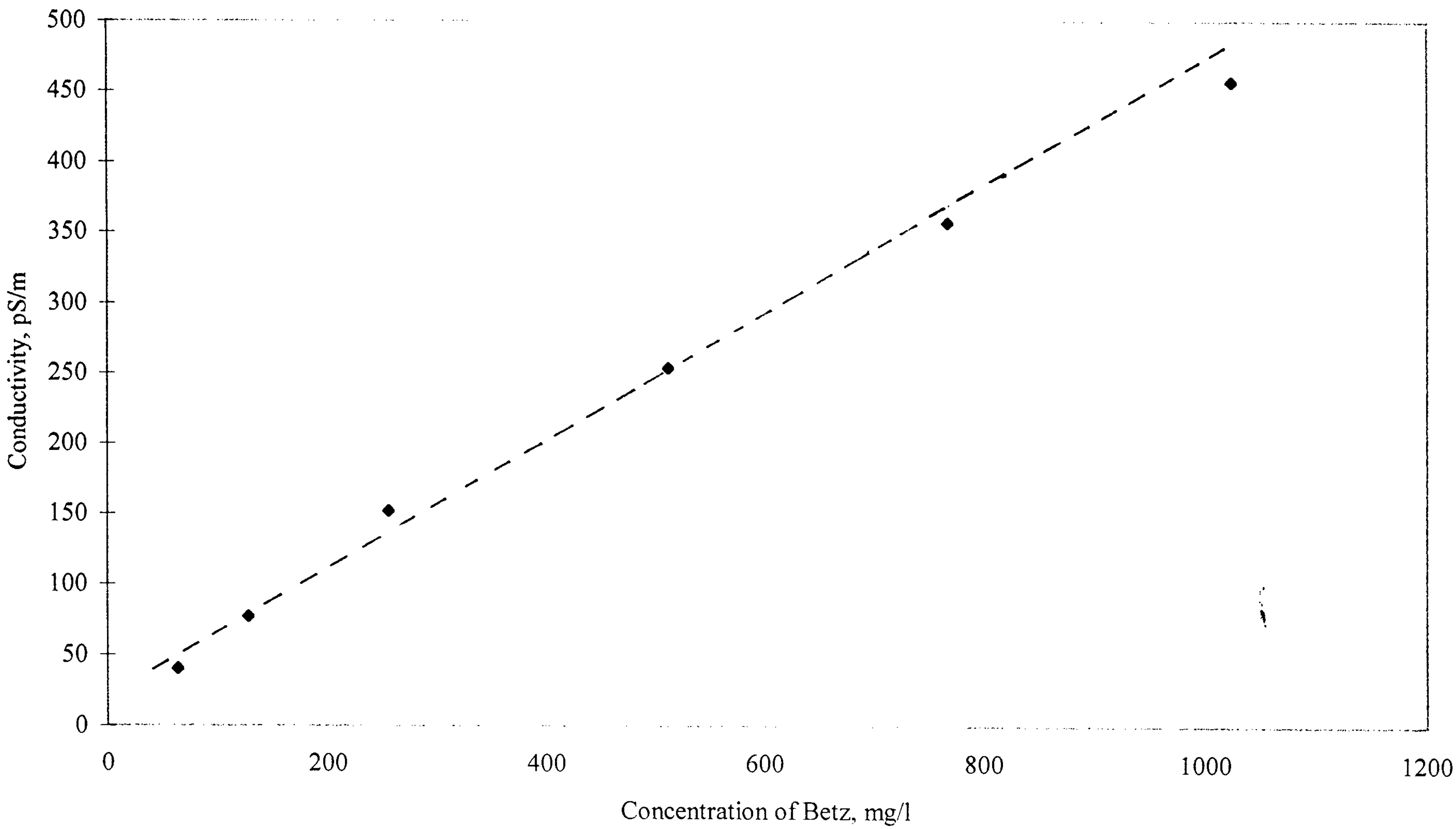


Fig. 6- Effect of Corrosion Inhibitors on Fuel Conductivity (Conductivity of Neat Fuel = 0.102 pS/m). Ref. 4

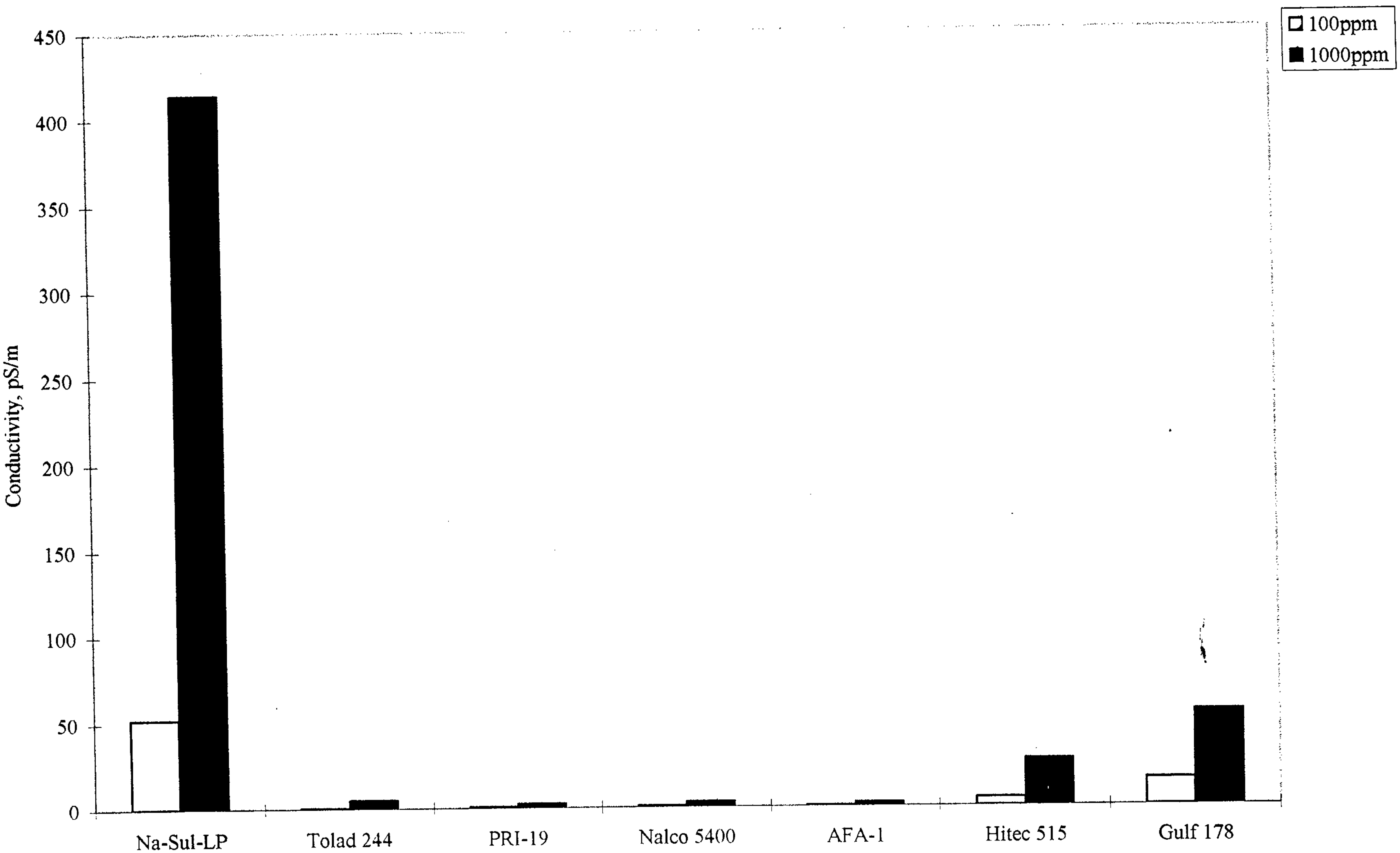
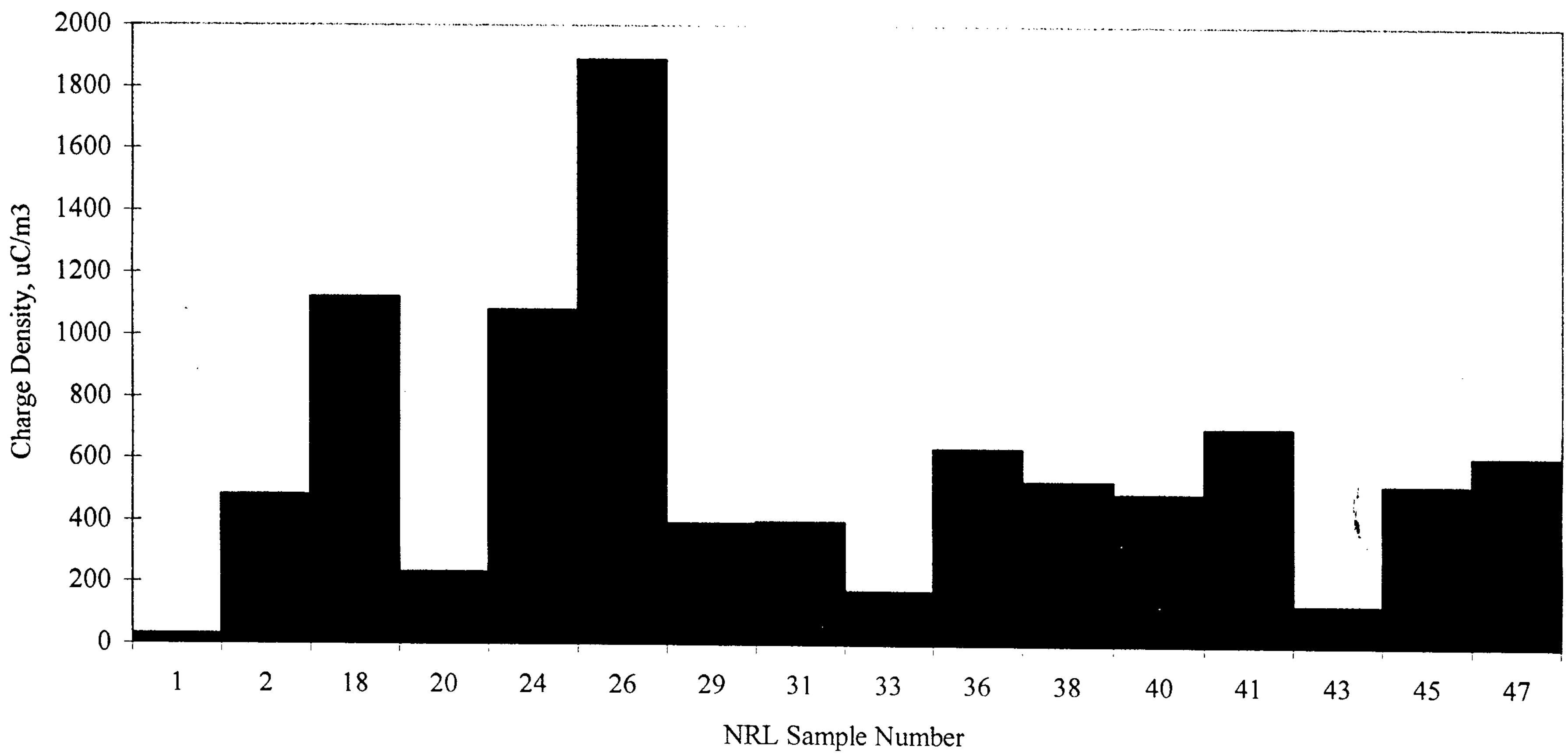


Fig. 7- Charging Tendency of Fuels Not Containing Betz Additive (Fuels in the Normal Jet A Conductivity Range Only) Filter: Type10 Paper



survey (3). In that survey, 99% of the Jet A samples had charging tendencies < 3000 μC/m^3 and the mean value was 680 μC/m^3. The exception in the present study was Sample 22, which also had a very high initial conductivity (322 pS/m) indicating that it probably contained a static dissipater additive.

For reference, a value of 4000 μC/m^3 has been selected as the threshold for high charging in the present study. This selection is based on the fact that only one sample out of a total of 338 Jet A samples in the 1975 CRC survey (3) had a charging tendency above 4000 μC/m^3.

Most of the samples containing the Betz additive had exceptionally high charging tendencies; most were over 10,000 μC/m^3 and up to a maximum of 26,100 μC/m^3 (Table 2 and Fig. 8). The highest values were obtained with the fuels having the highest conductivities, namely Samples 8, 10, 12, 13, 14, 15, and 17, which, as indicated above, probably contained Stadis 450 in addition to Betz. These values are in the range found for the most active fuel additive found in the previous study (4), namely Gulf 178, which was a corrosion inhibitor. This additive produced charge densities of 15,000 μC/m^3 at the 100 ppm level and 23,500 at the 1000 ppm level (Fig. 9).

The high charging indicated above for fuels containing the Betz additive is of little concern from the standpoint of an electrostatic hazard under <u>most</u> circumstances since the conductivities of the fuels are so high, i.e. above 90 pS/m. The high conductivity would permit most of the charge to dissipate in less than a second after it is generated. The possible exceptions where a hazard might occur despite the high conductivity are: during the filling of an empty filter vessel or when the fuel flows over a low conductivity reticulated foam.

The effect of the Betz additive on the charging tendencies of "normal" Jet A fuels using the Type 10 reference filter is seen more clearly in Table 3. The Betz additive increased the charging tendencies of eight of these samples above the 4000 μC/m^3 threshold, making them high charging samples. Curiously, one sample, Sample 26, had a decrease in charging tendency of 440 μC/m^3 after the addition of the Betz additive. For the remaining samples, the average increase in charging tendency was 5887 μC/m^3, a value somewhat skewed by two very high charging samples, i.e., Samples 40 and 46.

Although no overall correlation was found showing the effect of conductivity on charging tendency of fuels containing the Betz additive (Fig. 10), for a given fuel, the charging tendency was found to reach a maximum in the range of 150-250 pS/m (Fig. 11). This is in agreement with earlier work showing the effect of the static dissipater additive ASA-3 on the charging tendency of jet fuels (8) (Fig. 12).

Fig. 8- Charging Tendency of All Fuels Containing Betz Additive. Filter: Type 10Paper

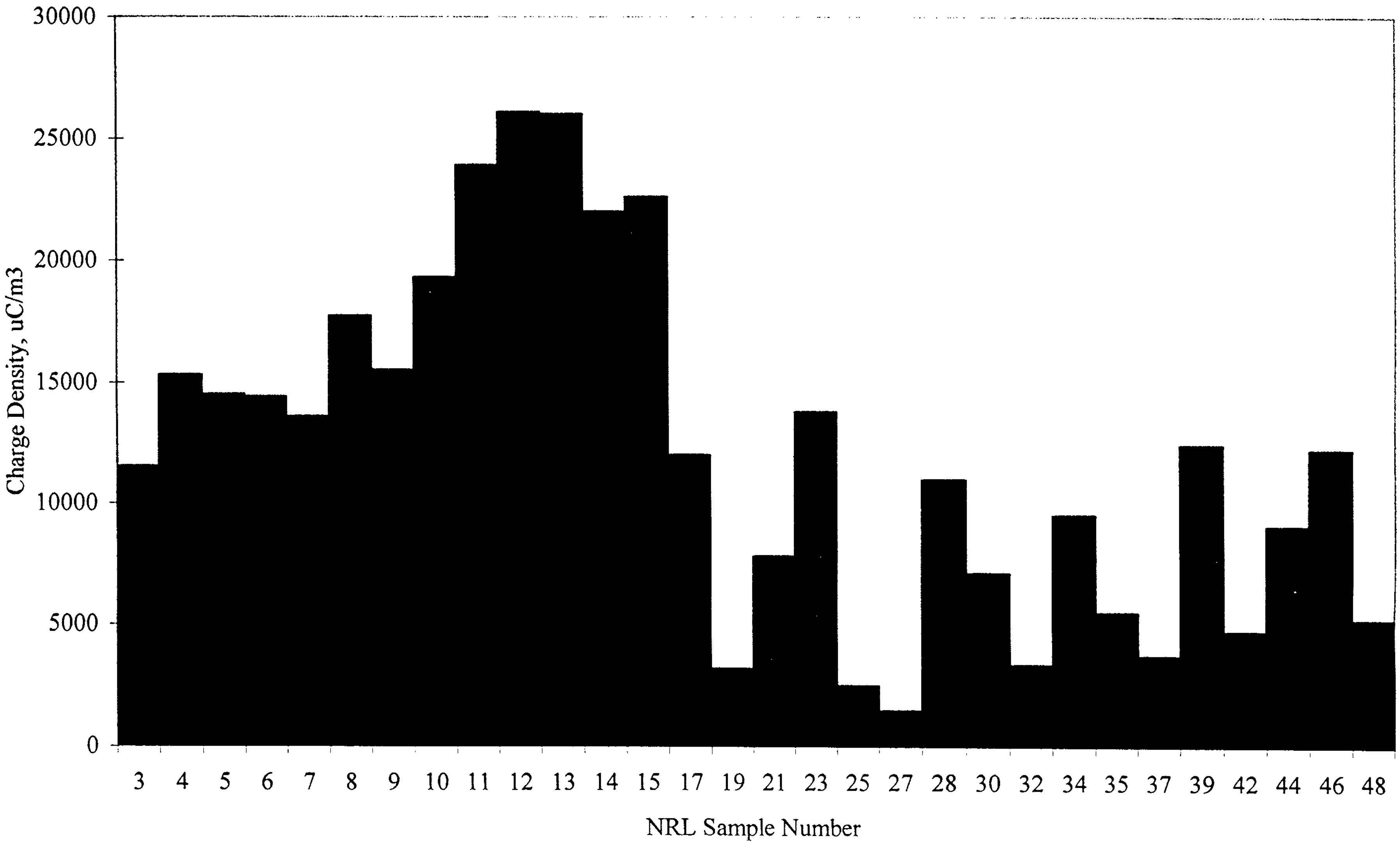


Fig. 9- Effect of Corrosion Inhibitors on Charging Tendency (Charge Density of Neat Fuel = 909 uC/m3). Filter: Type 10 Paper-Ref. 4

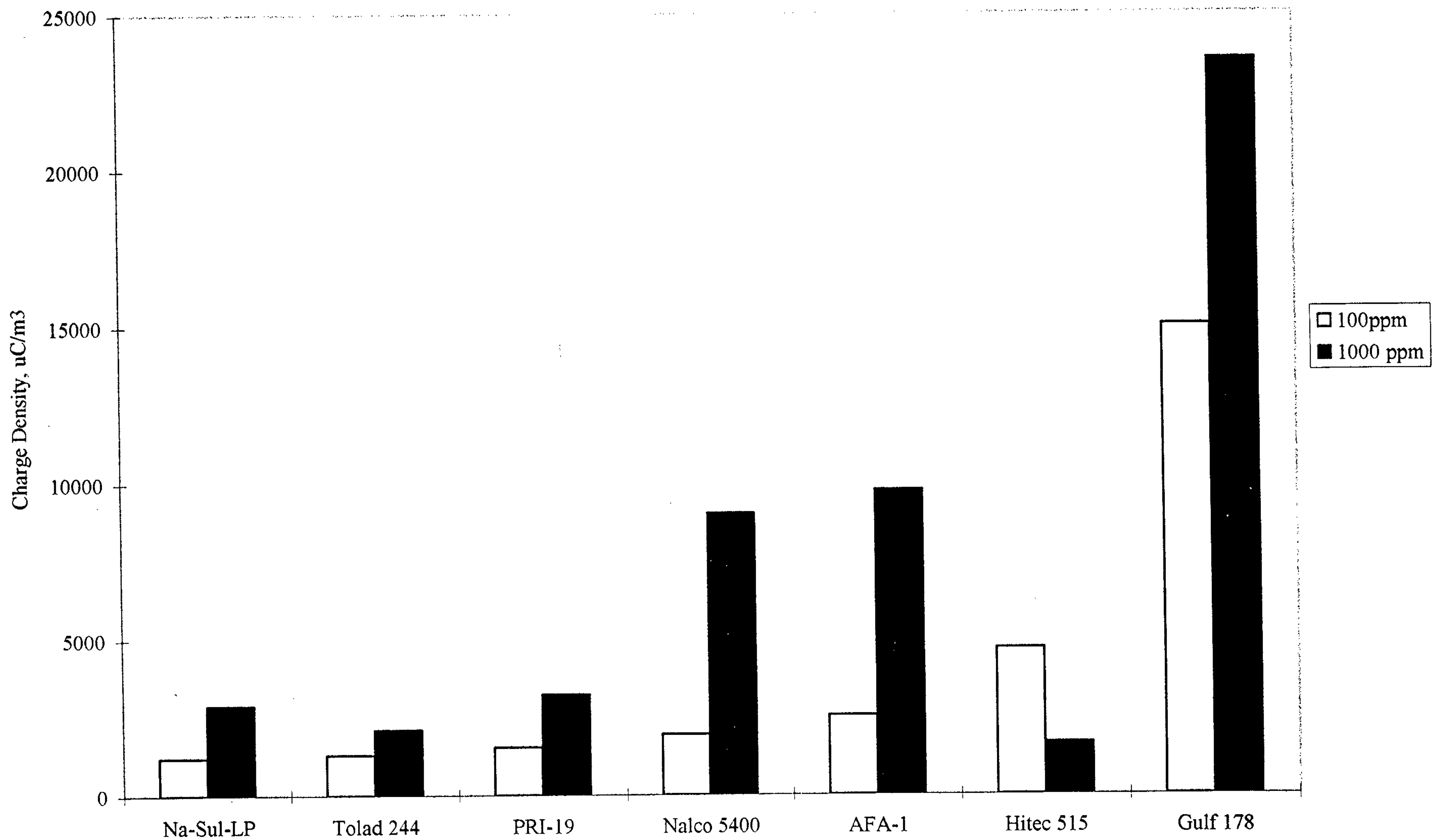


Fig. 10- Effect of Conductivity on Charging Tendency of Fuels Containing Betz Additive. Filter: Type 10 Paper

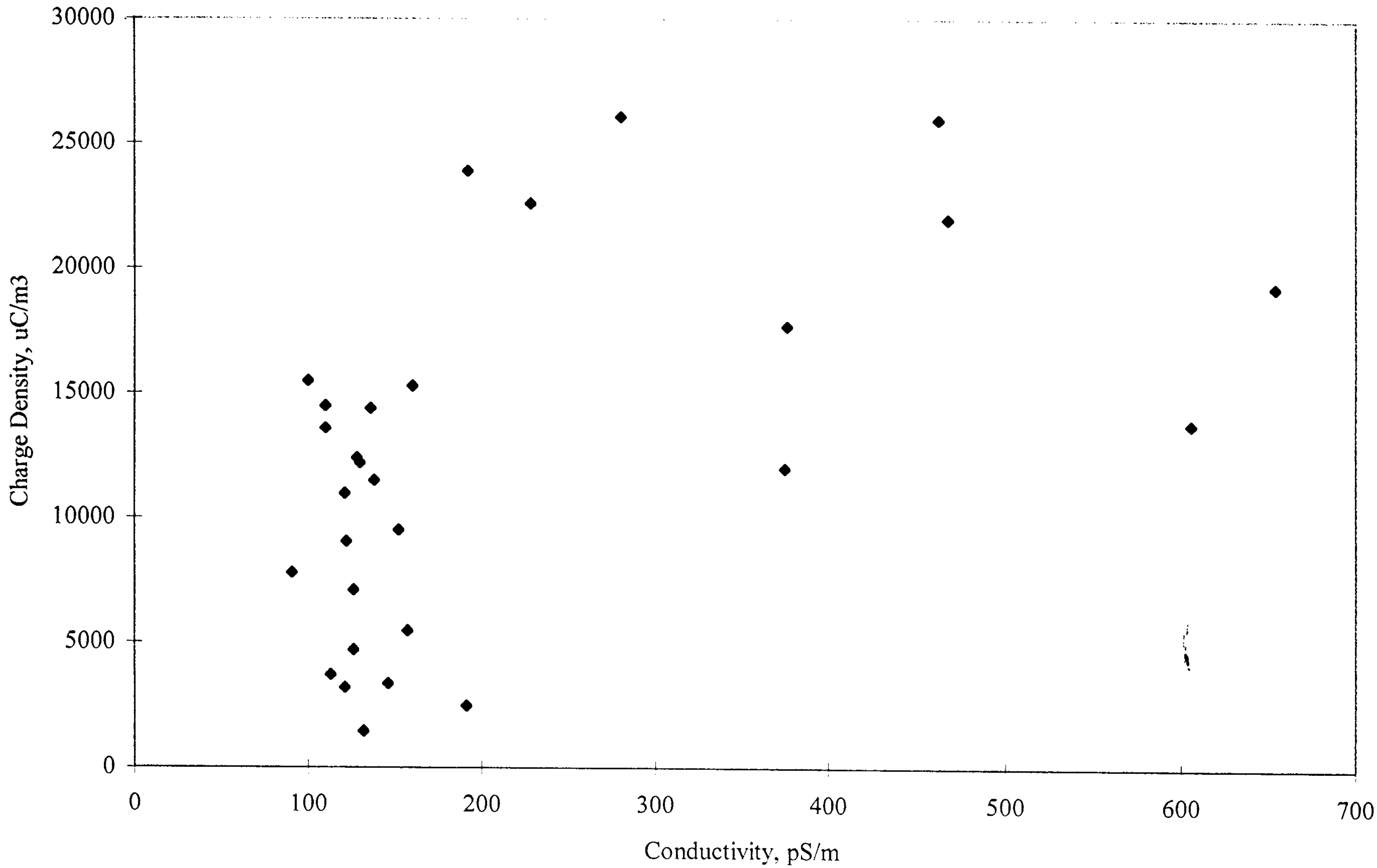
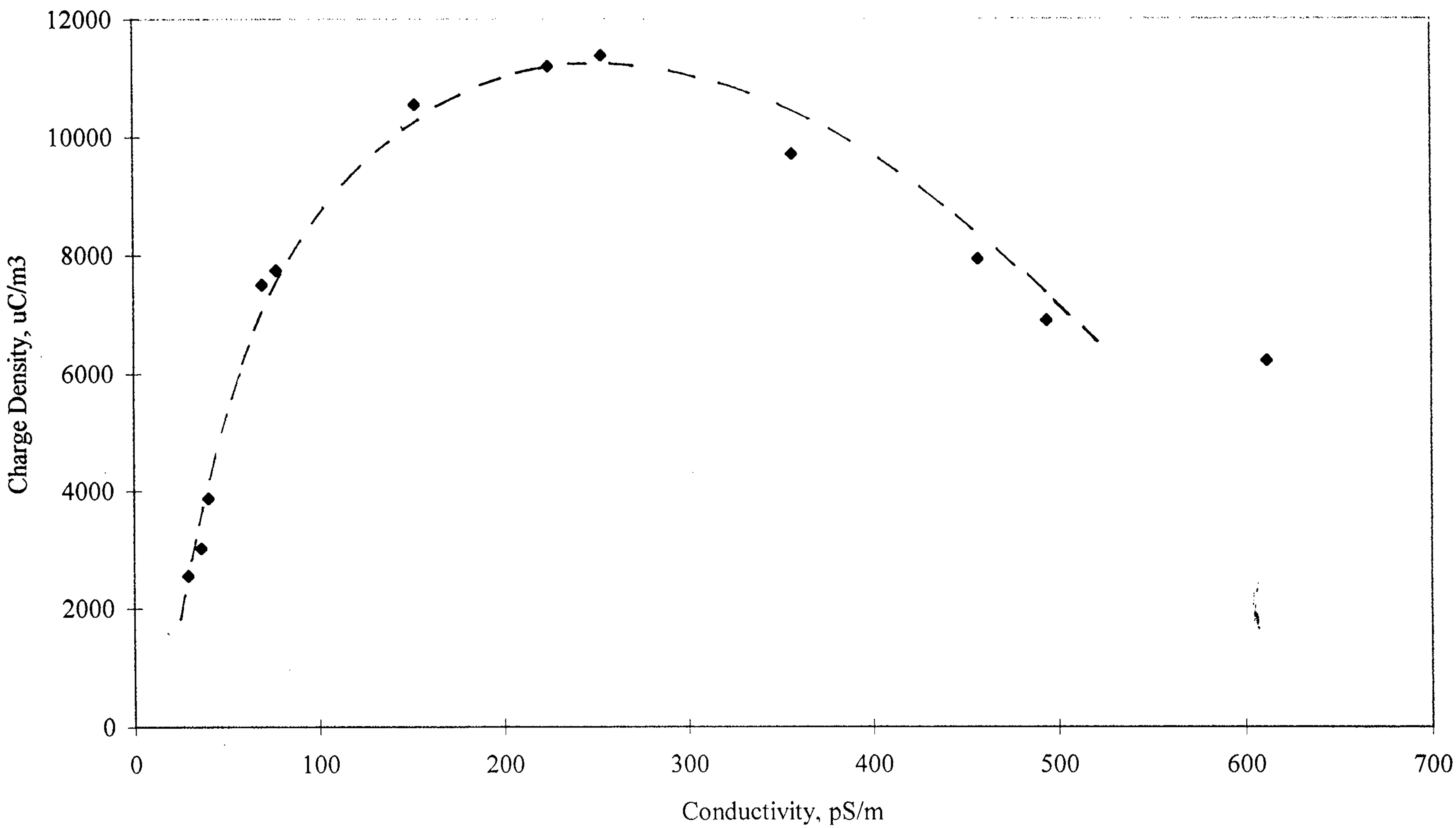


Fig. 11- Effect of Betz Additive on Charging Tendency of a Jet A Fuel (NRL Sample No. 34)



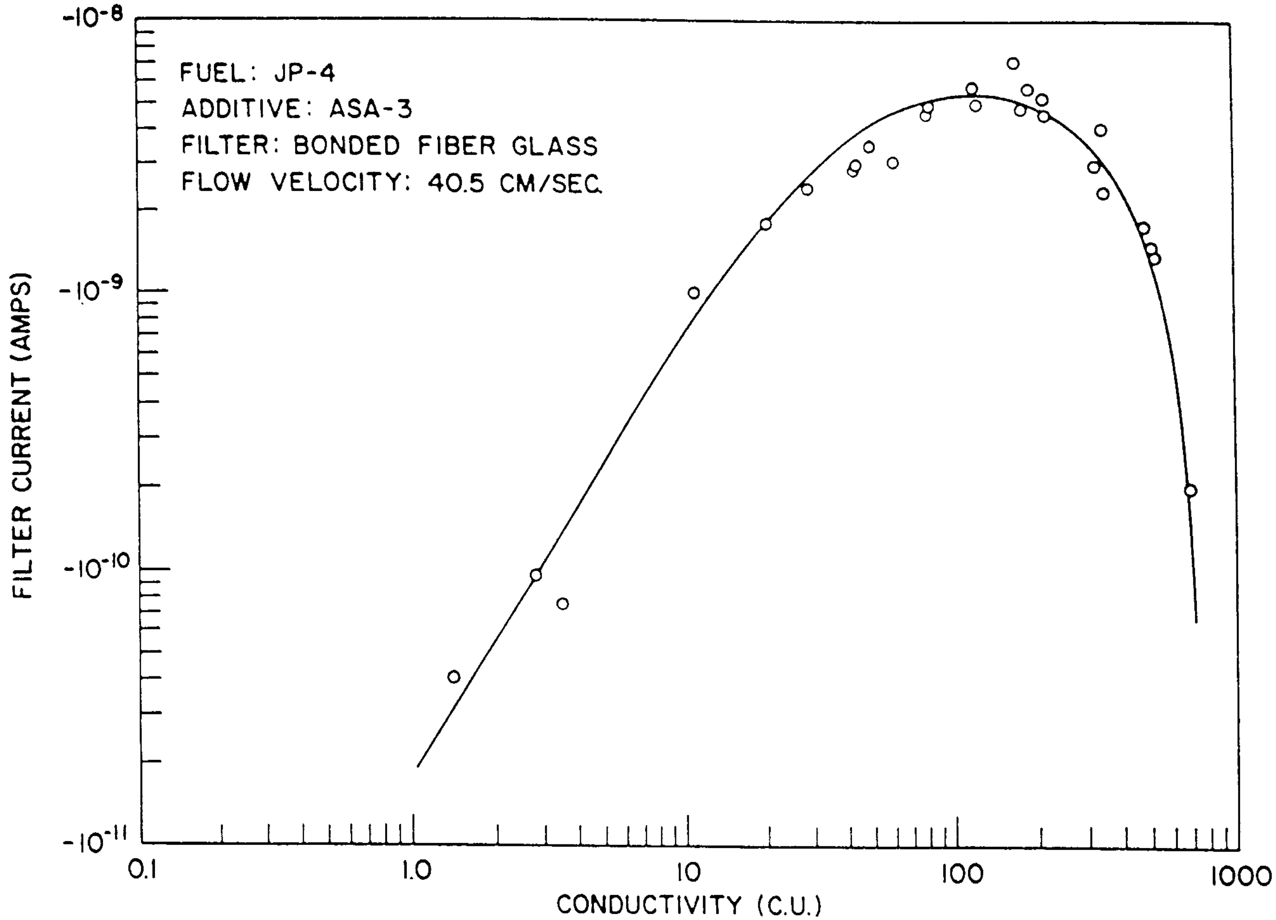


Fig.12 - Effect of conductivity of JP-4 fuel containing the static dissipator additive on filter current, gravity apparatus

Effect of Stadis 450 on Conductivity and Charging Tendency

The addition of 1 ppm Stadis 450 increased the conductivities of most samples to above 100 pS/m (Table 4, Fig. 13.) However, fuels varied widely in their response to Stadis 450. Three samples, namely, Samples 31, 33, and 45, showed poor conductivity response to Stadis 450 and Samples 31 and 33 also showed correspondingly low charging tendencies. The average increase in conductivity for samples in the normal conductivity range (0.1 - 10 pS/m) was 138 pS/m after the addition of 1 ppm Stadis 450, and five samples were above 150 pS/m.

Table 4 – Effect of 1 ppm Stadis 450 on Conductivity and Charging Tendency of Fuels Not Containing the Betz Additive (Filter: Type 10 Paper)

		Conductivity, pS/m			Charge Density, $\mu C/m^3$		
NRL* Sample No.	AF* POSF No.	Before Stadis	After Stadis	Δ k*	Before Stadis	After Stadis	Δ CD
A. Samples in Normal Jet A Conductivity Range							
1	3498 Neat**	0.15	230	+230	38	3,350	+3,312
2	3498	0.22	131	+131	480	6,160	+5,680
18	3551A	2.86	126	+123	1,120	1,700	+580
20	3552A	0.31	192	+192	231	5,280	+5,049
24	3554A	9.44	189	+180	1,080	>519***	+>561***
26	3555A	3.43	108	+105	1,890	6,100	+4,210
31	3627B	1.22	67.3	+66	397	738	+341
33	3633B	1.84	65	+63	171	720	+549
36	3638B	2.17	104	+102	634	3,700	+3,066
41	3593A	3.76	108	+104	702	2,500	+1,798
43	3601A	0.25	268	+268	131	>2,260	+2,129
45	3602A	0.43	70.6	+70.3	519	2,680	+2,161
47	3603A	1.00	167	+166	610	3,710	+3,100
B. High Conductivity Samples							
16	3550A	79****	255	176	>180***	1,190	+>1,010***
22	3553A	322****	611	289	5,950	4,180	-1770

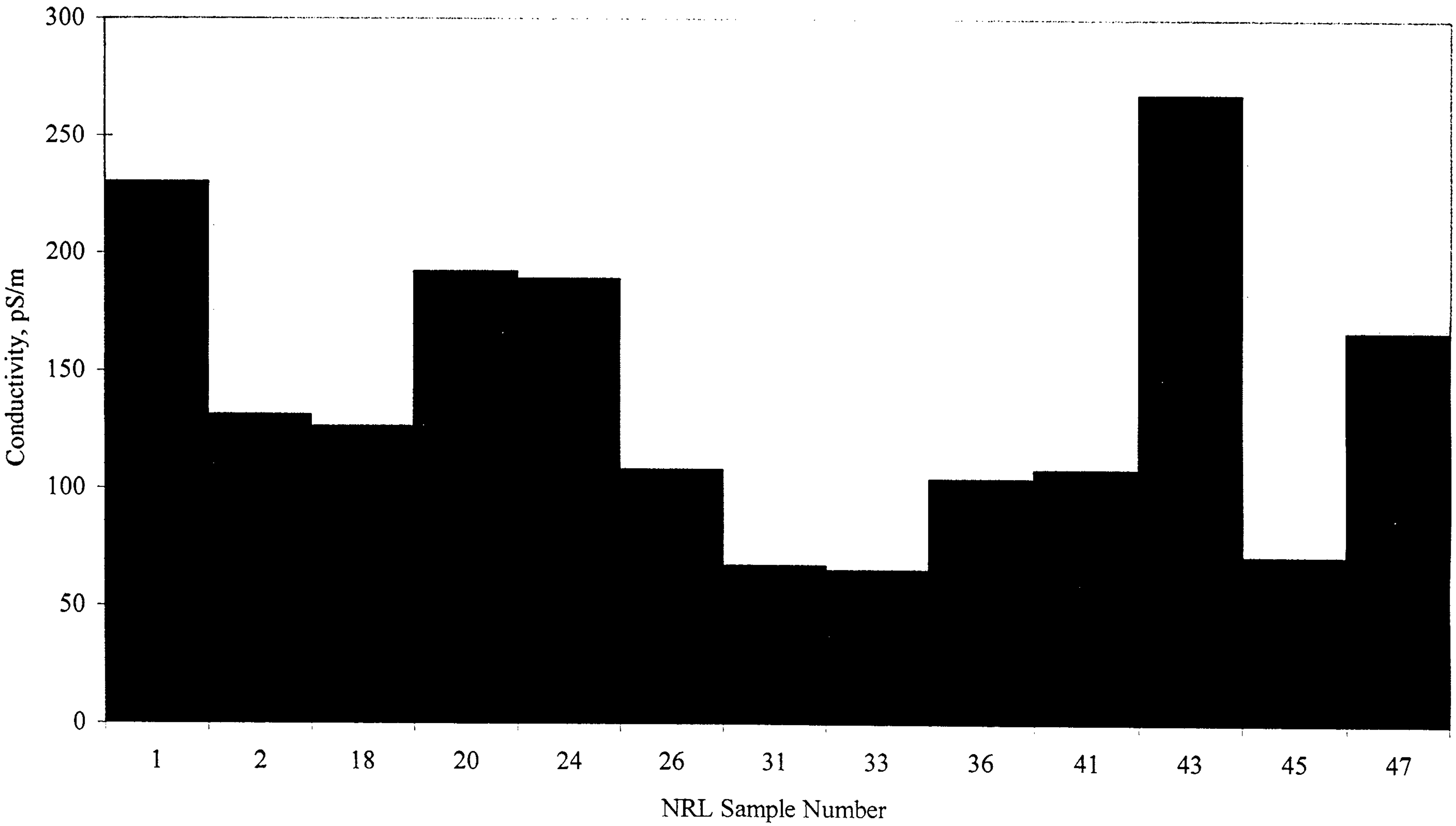
* Average Δk for samples in normal Jet A conductivity range: 138 pS/m

** This sample did not contain FSII or CI

*** Unable to achieve equilibrium with this sample

**** High initial conductivity suggests that this sample already contained Stadis 450

Fig. 13- Conductivity of Fuels Containing Stadis 450, But Not Betz Additive



The charging tendencies of fuels not containing the Betz additive increased over a wide range (519 - 6160 $\mu C/m^3$ (Table 4 and Fig. 14)) upon the addition of 1 ppm Stadis 450. Three of the samples, namely, Samples 2, 20 and 26, were above 4000 $\mu C/m^3$, and hence would be considered high charging. However, as with the Betz additive, the high charging would not be indicative of an electrostatic hazard under most circumstances as long as the conductivity of the fuel were sufficiently high.

For samples containing the Betz additive, the average increase in conductivity was 252 pS/m after the addition of 1 ppm Stadis 450 (Table 5 and Fig. 15). This is considerably more

Table 5 – Effect of 1 ppm Stadis 450 on Conductivity and Charging Tendency of Fuels Containing the Betz Additive (Filter: Type 10 Paper)

		Conductivity, pS/m			Charge Density, $\mu C/m^3$		
NRL* Sample No.	AF* POSF No.	Before Stadis	After Stadis	Δ k*	Before Stadis	After Stadis	Δ CD
A. Samples in the Normal Conductivity Range for Betz Additive							
3	2827	138	339	+201	11,500	20,500	+9,000
4	2926	160	382	+222	15,300	19,800	+4,500
5	3055	110	339	+229	14,500	19,200	+4,700
6	3119	136	380	+244	14,400	17,500	+3,100
7	3166	110	343	+233	13,600	16,300	+2,700
9	3084	100	352	+252	15,000	19,300	+4,300
11	3476	192	536	+344	23,900	23,000	-900
19	3551B	121	325	+204	3,210	13,200	+9,990
21	3552B	90.5	389	+298	7,810	16,600	+8,790
25	3554B	191	451	+260	2,490	9,210	+6,720
27	3555B	132	355	+223	1,452	6,770	+5,318
B. High Conductivity Samples							
8	3219	376**	565	+189	17,700	16,100	-1,600
10	3475	654**	906	+252	19,300	12,200	-7,100
12	3477	280**	562	+282	26,100	20,000	-6,100
13	3478	463**	739	+276	26,000	20,600	+600
14	3479	468**	778	+310	22,000	12,700	-9,300
15	3480	228**	504	+276	22,600	24,300	+1,700
17	3550B	375**	550	+175	12,000	9,760	-2,240
23	3553B	606**	921	+315	13,800	10,200	-3,600

* For samples containing the Betz additive: Range, 175-344 pS/m; Average, 252 pS/m

** High initial conductivity indicates that this sample may have been previously treated with Stadis 450

Fig. 14- Charging Tendency of Fuels Containing Stadis 450, But Not Betz Additive. Filter: Type 10 Paper

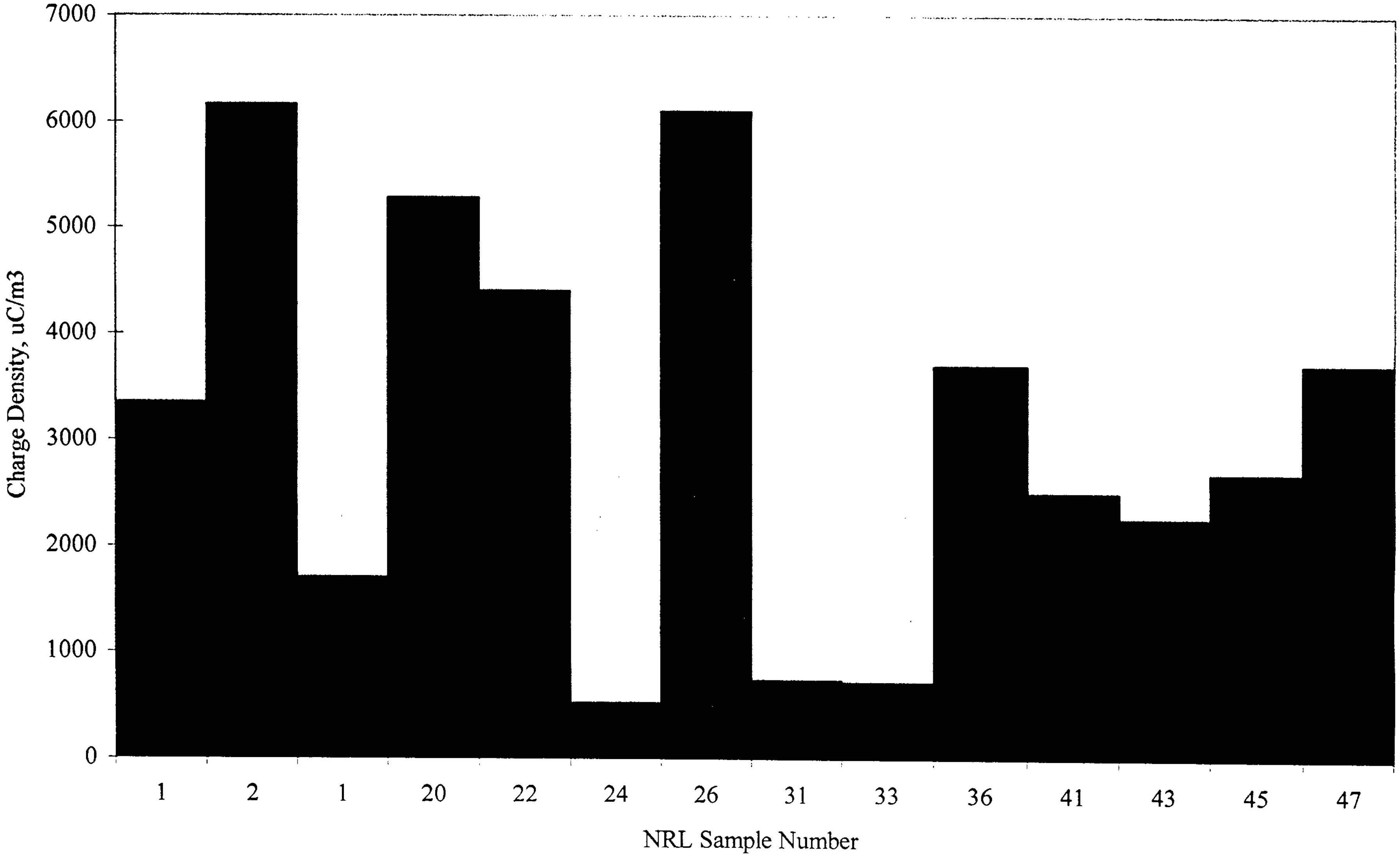
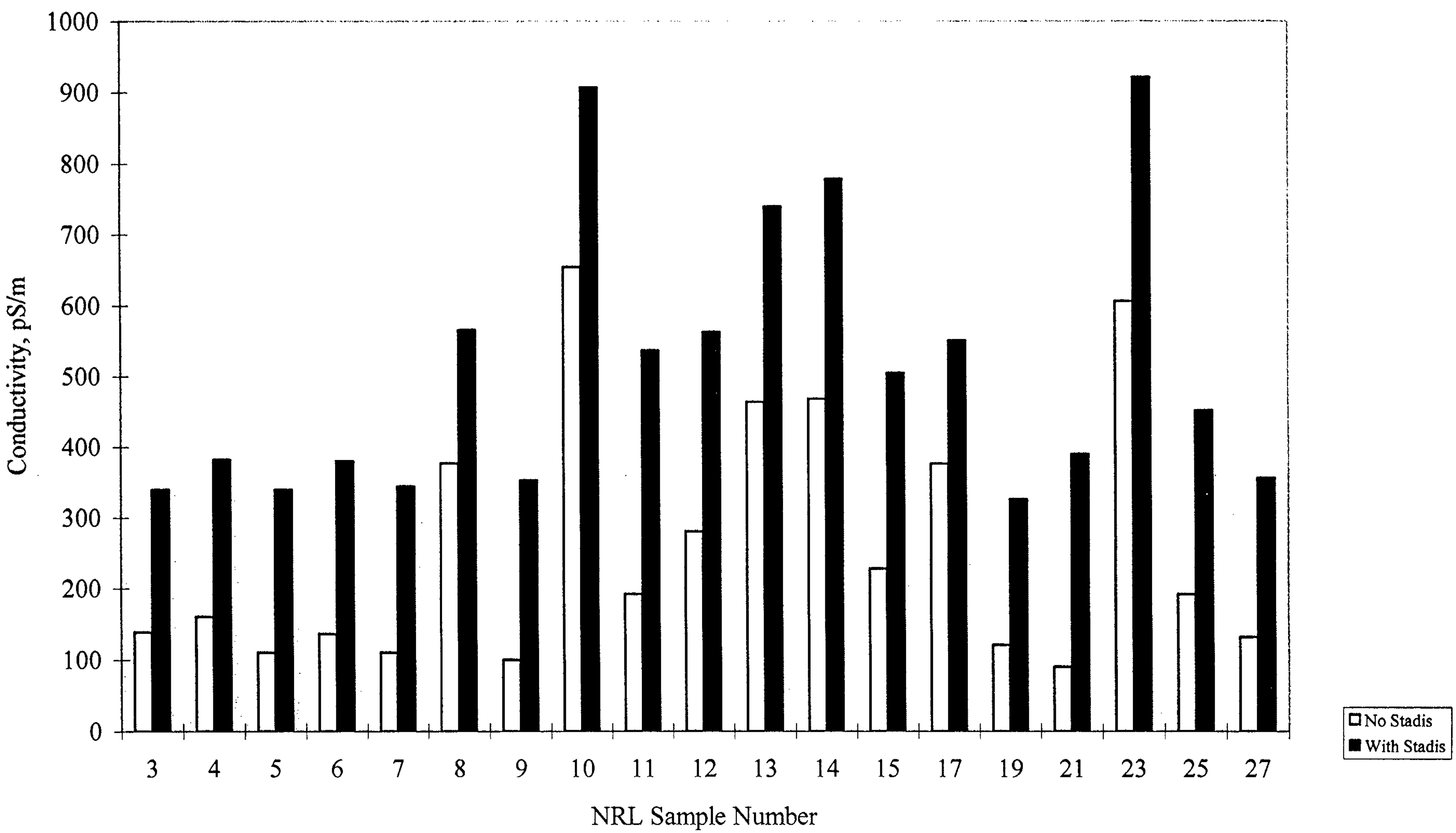


Fig. 15- Effect of 1 PPM Stadis 450 on Conductivty of Fuels Containing Betz Additive



than the increase of 138 pS/m obtained when Stadis was added to fuels not containing the Betz additive, indicating that Stadis is more active in fuels containing the Betz additive. Some of the samples, e.g. Samples 8, 10, 12, 13 14, 15, 17 and 23, had unusually high conductivities before the addition of Stadis 450, indicating that they may have been previously treated with Stadis 450.

The addition of 1 ppm of Stadis 450 increased the charging tendencies of most of the samples containing the Betz additive except for the high conductivity samples, i.e., above 280 pS/m (Table 5, Fig. 16). As shown earlier (Figs. 11 and 12), the charging tendency of a fuel containing a particular additive increases with conductivity up to a certain conductivity level, depending on the flow velocity, and then begins to fall off at higher conductivities. For the flow velocity used in this study, the charging tendency begins to fall off above 250 pS/m for fuels containing the Betz additive (Fig. 11).

The charging tendencies for fuels containing both Betz and Stadis were all quite high, in the range of 6770 – 24,300 $\mu C/m^3$ (Table 5). However, such high charging is of little concern from the standpoint of an electrostatic hazard under <u>most</u> circumstances, as explained above, since the conductivities of the fuels are all so high (above 325 pS/m).

Charging Tendency Measurements on Various Filter Media

Charging tendency measurements were made on coalescer, separator and monitor cartridge media supplied by three manufacturers. In addition, an experimental coalescer material, designated "Type 1," was also tested. Although the media were intended for use on JP-8 + 100 fuels, three different types of fuels were tested:

1) Fuels not containing Betz or Stadis 450

2) Fuels containing Betz but no Stadis

3) Fuels containing Stadis but no Betz.

All samples contained FSII and CI unless indicated otherwise.

The results of the charging tendency measurements for fuels on the various filter media are given in Table 6. The symbols (< and >) preceding the charge density values for certain samples indicate that equilibrium was not achieved for these samples after three passes of fuel through the filter: the > symbol indicates that the filter current was still increasing after three passes of the fuel, and the < symbol means that the current was still decreasing after three passes. The current reading at the end of the third pass was used to calculate the charge density value shown in the table.

Fig. 16- Effect of 1 PPM Stadis 450 on Charging Tendency of Fuels Containing Betz Additive. Filter: Type 10 Paper

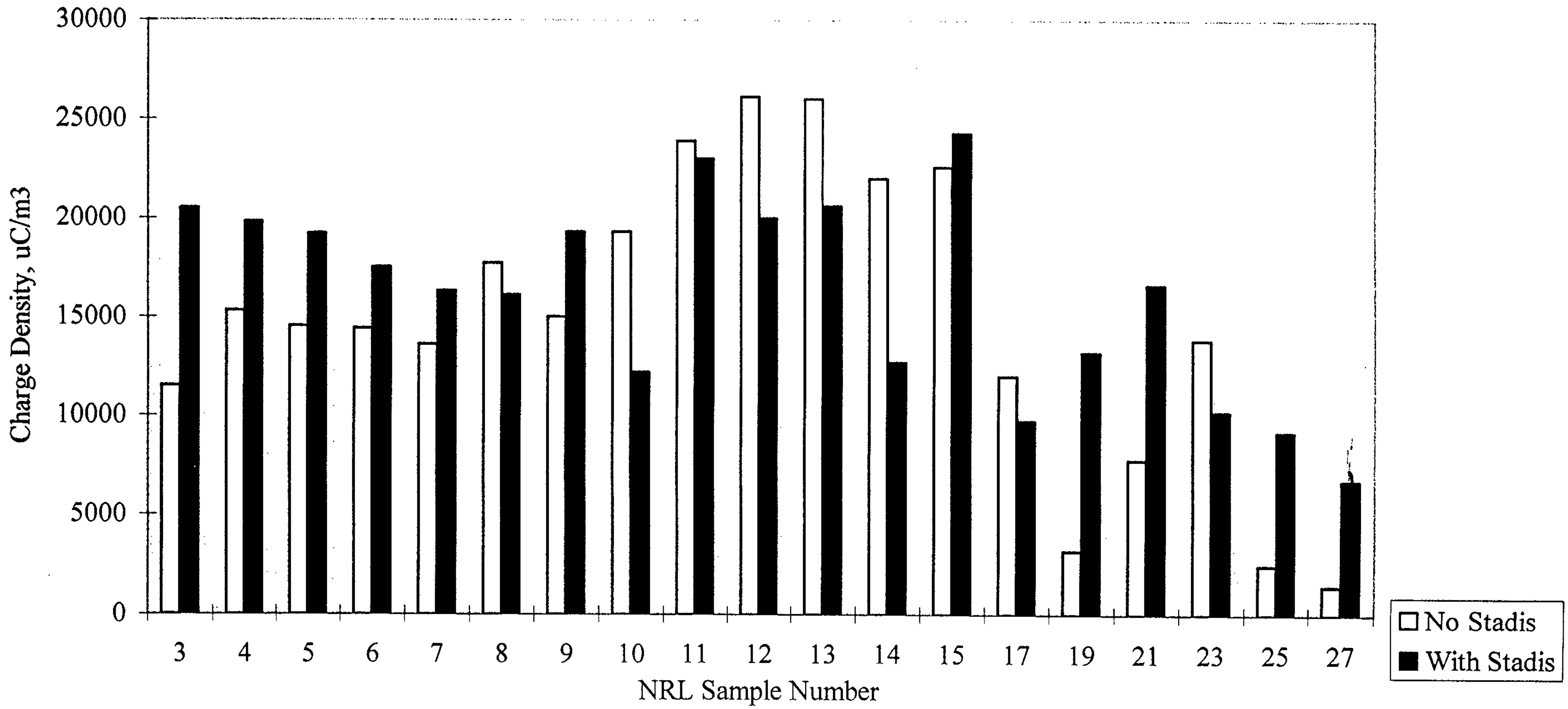


Table 6 – Charging Tendency of Fuels on Coalescer Media

NRL Sample No.	2D	29	28	30	34	31*	33*	38*	40**	97-55**+	47*
AF POSF No.	3428D	---	3166	3627A	3638	3627B*	3633B*	3639B*	3640B**		3603*
	Samples with no Betz or Stadis		Samples with Betz, no Stadis			Samples with Stadis, no Betz					
Conductivity, pS/m	0.22	4.25	121	126	152	65	65	86	99	101	167
Description of Medium	Charge Density, $\mu C/m^3$										
5 oz. Felt	-2		<55	451	<27	-2,170	-1,270	-3,800	-1,680	-3,360	
8 oz. Felt	-4	-46	324	145	>-366	-3,770	-3,230	-4,030	-3,040	-2,140	
10 oz. Felt	-4	-18	>-305	>445	>-598	-7,080	-5,120	-9,940	-7,320	-7,750	
Fiberglass, Coarse	-4	-67	>-268	>244	<48		-683			-2,010	
Fiberglass, Fine	-3		>515	101	-6		-1,400			-9,760	
Fiberglass, Fine	>2	>1,100	>-1,450	238	92		-1,510			-15,600	
Fiberglass Screen			9								
Fiberglass Paper, Top	-16	-472	-720	N/A	-671	-2,560		-4,100			-4,700
Fiberglass Paper, Mesh	-18	-381	-860	N/A	418	>-3,840		-6,100			-5,550
Fibrous Material	-4	-329	-586	N/A	>-37	-3,380		-6,700			-9,330
Glass Substrate	-24		-720	-195	-347		-2,200		-3,430	-3,569	
Glass Substrate	-18		-641	>-50	>-223		-1,710			>-4,390	
Glass Sheet	-32		1,040	-305	>-407	-4,390	-2,540		4,070	-3,750	
Knit (Cotton), Off-White	0	-12	-30	N/A	-9	-1,020	-1,120	-1,040			-189
Knit (Synthetic), White	3	-52	>-488	N/A	100	>-3,870	-4,850	-4,320			-287
Polyester	0	5	<33	171	<26		-622			-799	
Polyester	-4		-302	-87	-317		-1,550			-1,070	
Polyester Non-Woven Sleeve A	-18	-132	-404	-154	-262	-5,110		-7,750			
Polyester Non-Woven Sleeve B	-5	-14	-132	-130	-43	-732		-1,100			
Polyester Spun Bound	2		118							409	
Prefilter Extruded Net	-0.6	0	10	<10	16	-85		-96			
Prefilter Glass Fiber Material	1.5	4	<21	<111	75	-142		>-458			
Prefilter Non-Woven Material	-30	-350	-1,460	-1,710	-1,190	>-3,540		>-4,510			
Screen, Aluminum			8								
Sock, Cotton	-2		13							1,530	
Type 1 Coalescer Medium	155	1220	>19,800	>22,500	>21,700	>1,190		>4,390			

+ NRL 97-55 is a Jet A with no additives
* Plus 1 ppm Stadis 450
** Plus 2 ppm Stadis 450

An example of a rising filter current is shown in Fig. 17 which is the curve obtained for Sample 28 on Type 1 experimental coalescer material. In this case, the charging tendency reported in Table 6 for Sample 28 (> 19,800 $\mu C/m^3$) is the value calculated from the final filter current (-3.45 x 10^{-8}) on Fig. 17, which, as shown in the figure, appears to be reaching equilibrium at the end of the run. This sample produced a flat, equilibrium filter current on the Type 10 reference paper as shown in Fig. 18. In this case, the charge density is calculated from the current reading midway through the test as required in the test procedure (2). The reason why the fuel does not come to equilibrium on the Type 1 filter appears to be related to the fact that this filter is denser than the Type 10 medium, and hence has more surface area available for the charge separation process to occur on. Hence, more time is required for equilibrium to take place with this type of filter than is currently available using the EXXON Mini-Static Test procedure.

It should be noted that the EXXON Mini-Static Tester was designed to measure the charging tendency of a fuel on a single layer of filter medium, such as the Type 10 reference filter. In practice, most filters consist of several layers of different media. The subsequent layers can either augment the charging of the fuel if they produce the same sign of charge as the initial filter medium, or decrease the overall charge if they happen to produce charge of the opposite sign to the initial filter. The EXXON Mini-Static Tester would show the net effect of the charging by the different layers, assuming of course, that equilibrium was reached during the relatively short flow time of 30 seconds used by the Mini-Static Tester.

Charging on Fuels Containing Neither Betz nor Stadis

As shown in Table 6, fuels containing neither Betz nor Stadis produced low levels of charge on all coalescer media, including Type 1 coalescer medium. These same fuels (Samples 2D and 29) produced low levels of charge on Type 10 paper - see Table 1. Previous studies have shown that fuels that charge poorly on Type 10 paper, also charge poorly on other coalescer media (4).

Charging of Fuels Containing the Betz Additive

Fuels containing the Betz Additive, but no Stadis, produced low levels of charge on all coalescer media except the experimental Type 1 medium. The levels of charge obtained on this material (>19,000 $\mu C/m^3$) were higher than the values obtained with most fuels on the Type 10 paper - see Table 2. Hence, a more detailed study of charging on the Type 1 coalescer medium was carried out and is discussed later in this report.

Charging of Fuels Containing Stadis 450

The charge levels obtained for fuels containing Stadis 450 were generally higher than the values obtained with the Betz additive on all coalescer media except the experimental Type 1 medium. Of particular interest is the high charging obtained with the Stadis additive on the white knit synthetic material. Normally, knit materials are fairly low charging. Also, high charging was obtained for samples containing Stadis 450 on fiberglass and felt. In fact, charging

Fig. 17-Rising Filter Current for Fuel Sample 28 Using Type 1 Filter

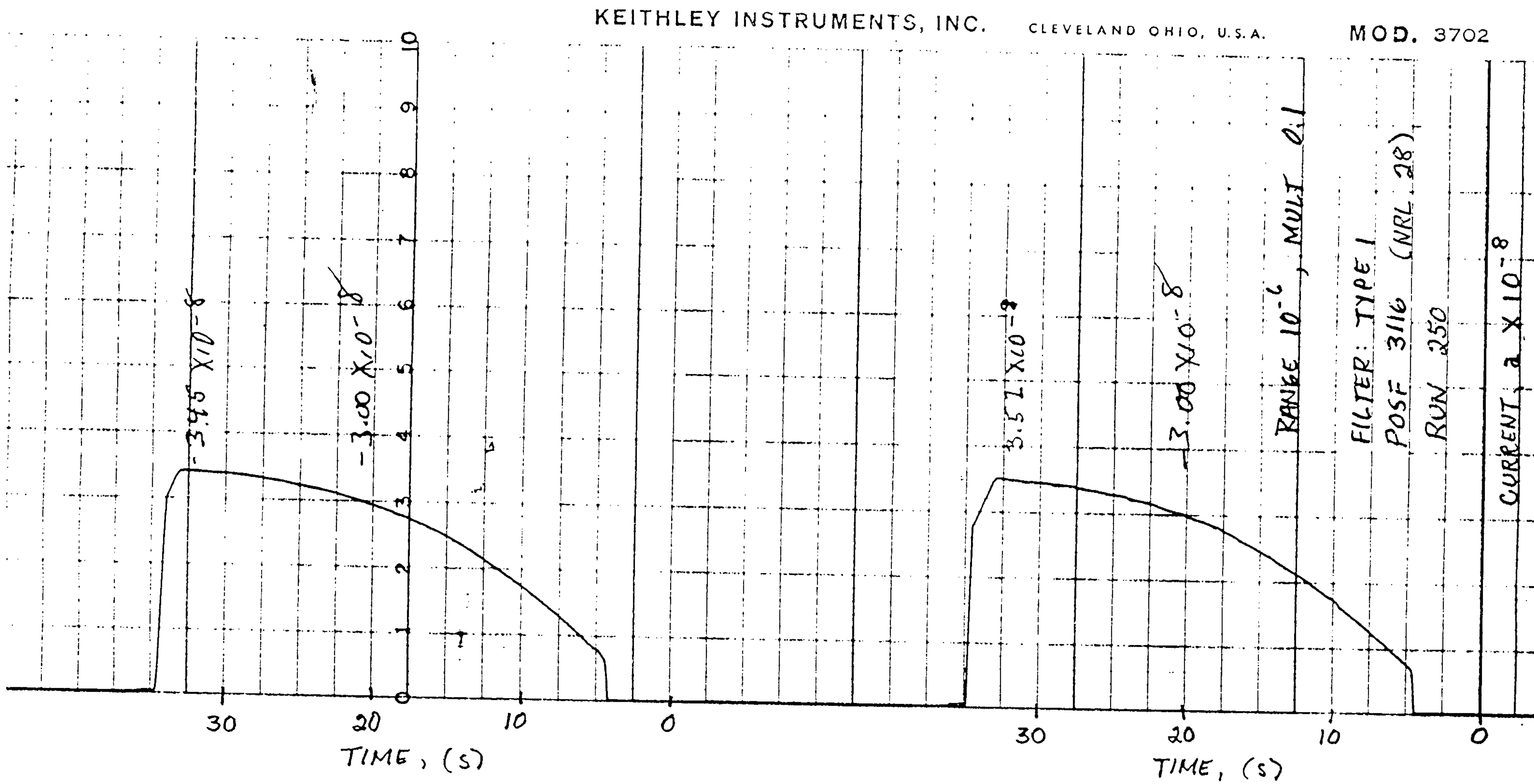
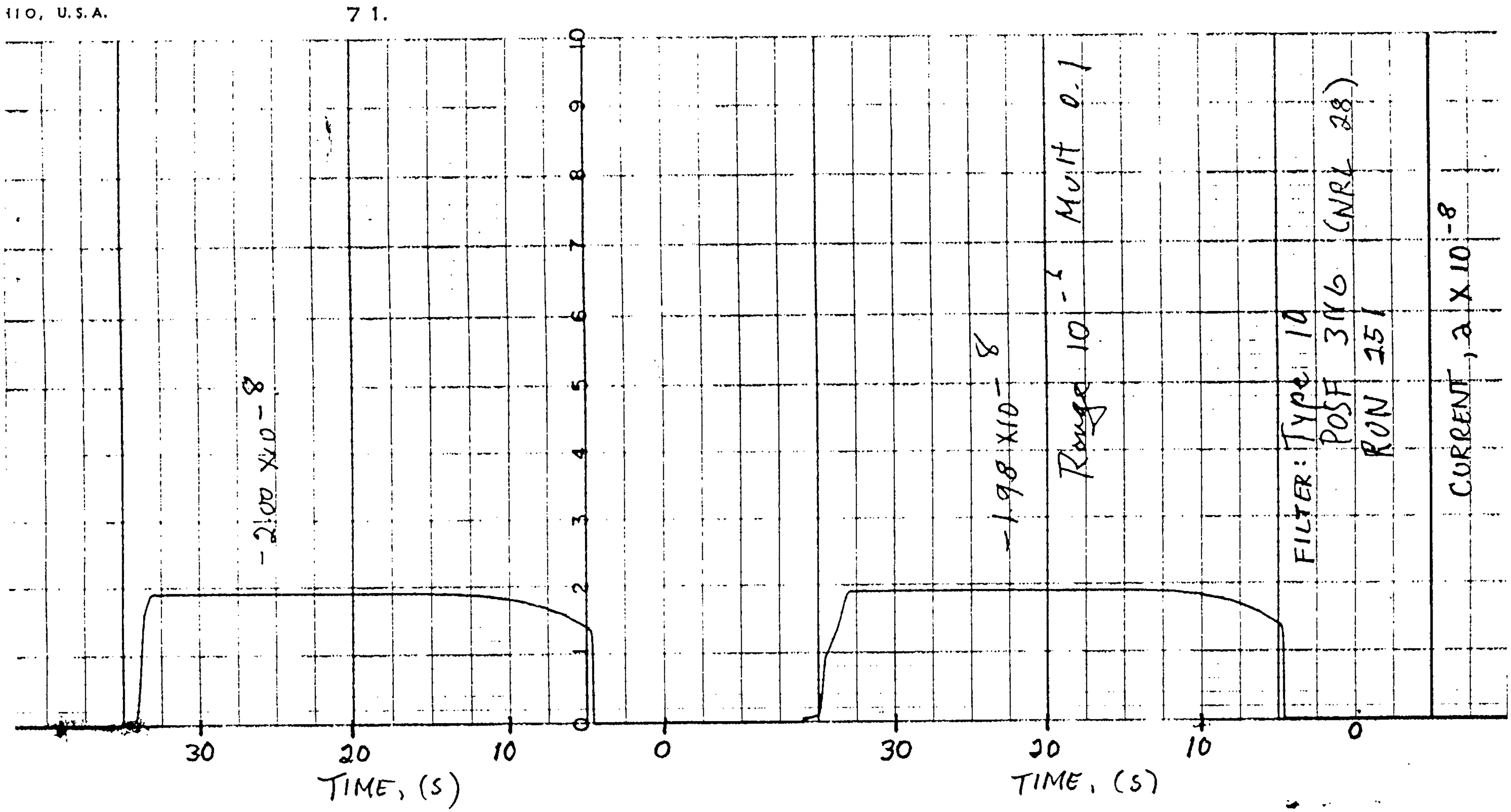


Fig. 18-Normal (Flat) Filter Current Curve for Fuel Sample 28 Using Type 10 Filter



of fuels containing Stadis 450 on felt appears to be related to the density of the felt (Fig. 19): the heavier the felt, the higher the charging.

Charging on Separator Media

As expected, no significant charging was found for any of the fuels on any of the separator media except Type 10 (Table 7). This is because all of the separator media, except Type 10 paper, have a fairly open structure with relatively low surface area on which charge separation can take place. The high charging on the Type 10 paper was the reason this paper was selected as a reference filter for testing the charging tendency of fuels.

Charging on Monitor Cartridge Media

Charging of the fuels with no additives and with fuels containing the Betz additive was low on all of the monitor cartridge media (Table 8). However, high charging was found for certain fuels containing Stadis 450 on the media paper (Layer 4) and on the superabsorbent and absorbent media (Layers 5 and 6) using Sample 36. A second series of tests using the same base fuel and 2 ppm Stadis 450 didn't show much increase in charging on Layer 4, but did show a decrease in charging on Layers 5 and 6. The decrease is due to the high conductivity of the fuel (373 pS/m). As explained earlier, the charging tendency begins to fall off as the conductivity goes above 250 pS/m (Fig. 11).

Comparison of Charging on Type 10 and Type 1 Filter Media

Since high charging was observed during the preliminary testing with the Type 1 experimental coalescer medium, a series of tests were conducted to compare the charging tendency of fuels on this medium with charging on the standard Type 10 filter. Several different fuels were used, namely:

1) Fuels containing neither Betz nor Stadis

2) Fuel containing Betz, but not Stadis

3) Fuel containing Stadis, but not Betz

4) Fuels containing both Betz and Stadis

The results of these tests are given in Tables 9-12.

Fig. 19- Charging of Fuels Containing 1 PPM Stadis 450 on Felt Coalescer Medium

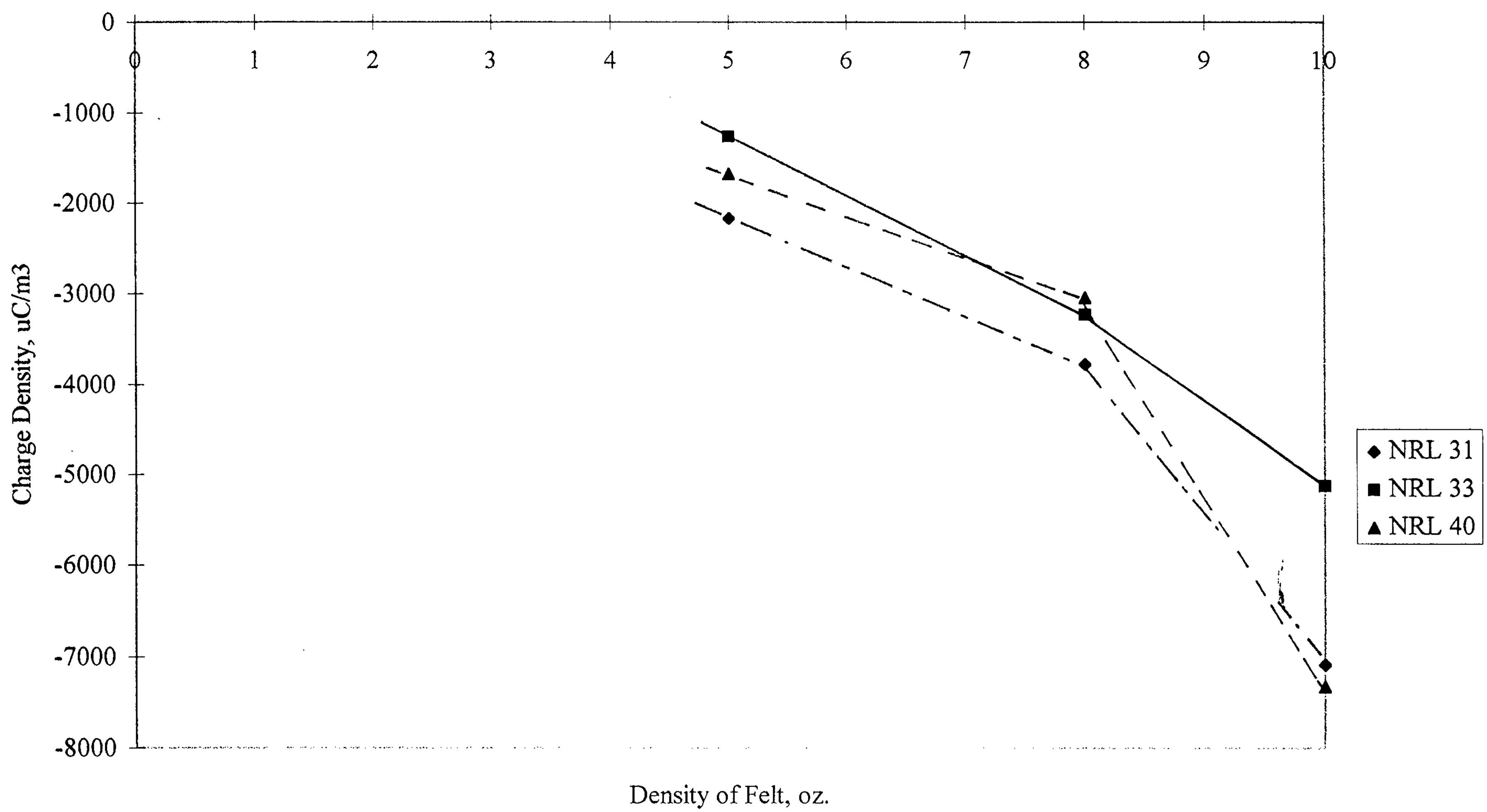


Table 7 – Charging Tendency of Fuels on Separator Media

NRL Sample No.	**2D**	**31**	**40**	**28**	**34**	**38**	**47**	**28 + 1 ppm Stadis**	**10/11 + 1 ppm Stadis**
AF POSF No.	**3428D**	**3627B**	**3640B**	**3166**	**3638A**	**3639B**	**3603A**	**3166 + Stadis**	**3475/3476 + 1 ppm Stadis**
	Samples with no Betz or Stadis			**Samples with Betz, no Stadis**		**Samples with Stadis, no Betz**		**Sample with Betz and Stadis**	
Conductivity, pS/m	0.22	1.22	6.10	121	152	86	167	342	452
Separator Medium	Charge Density, $\mu C/m^3$								
Teflon-Coated Screen	0	3	-3	6	15	-73	-32	17	11
Nylon-Treated PVO Screen	2	4	-2	442	125	-201	93	1,100	34
Type 10 Reference Paper	348	397	488	10,980	10,700	454	3,710	17,980	22,700

Table 8 – Charging of JP8 Fuels on Monitor Cartridge Media

NRL Sample No.		2D	2B	33	40	39	28	32	34	2B*	1*,**	36*	36***
AF POSF No.		3428D	3428B	3633B	3640B	3640A	3166	3633A	3638	3428B	3428*	3638B*	3638B + 2 ppm Stadis
		Samples with no Betz or Stadis				Samples with Betz, no Stadis				Samples with Stadis, no Betz			
Conductivity, pS/m		0.22	0.81	1.84	6.10	128	131	146	152	55.4	176	104	373
Cartridge													
Layer	Description	Charge Density, $\mu C/m^3$											
1	25 Micron Paper	-27	-75	-70	-95	>3,660	-381	-272	>-134	-793	-695	-2,300	>-35
2	Absorbent Media	-4	-9	-16	-80	0	-67	-33	-17	-580	-311	-1,230	-134
3	Media Paper	-3	6	-9	-21	>233	246	-6	0	-204	-73	>10	>29
4	Media Paper	-2	34	>-37	-80	>1,650	>-439	216	66	-500	-256	>11,700	>12,200
5	Media Superabsorbent (Polyolefin)	-22	-75	-171	-280	-123	-125	-280	-176	-2,740	-1,930	-4,010	-952
6	Media Absorbent	-12	-11	-108	-300	-66	-186	-134	-127	-2,260	-2,110	-4,260	-534
7	Media Spun bound Polyester	-1	-6	-15	-27	605	>-165	0	13	-280	-211	-50	-73

* Plus 1 ppm Stadis 450
** Sample 1 contained no FSII or CI
*** Plus 2 ppm Stadis 450

Table 9 – Charging Tendency of Fuels Not Containing Betz or Stadis 450 on Type 10 and Type 1 Filter Media

NRL Sample No.	AF POSF No.	Conductivity, pS/m	Filter Medium	
			Type 10	Type 1
			Charge Density, μC/m^3	
18	3551A	8.73	866	>1,830
20	3552A	0.14	290	101
24	3554A	7.35	793	1,090
26	3555A	2.33	1,530	>2,440
2D	3428B	0.81	573	436
2D	3428D	0.22	348	155
97-55		0.63	677	1,070
29		4.25	392	>1,220
31	3627B	1.22	397	>445
33	3633B	1.84	171	205
36	3638B	2.17	634	>281
38	3639B	2.30	528	>2,074
40	3640B	6.10	488	>427

Table 10– Charging Tendency of Fuels Containing Betz, but not Stadis 450, on Type 10 and Type 1 Filter Media

NRL Sample No.	AF POSF No.	Conductivity, pS/m	Filter Medium	
			Type 10	Type 1
			Charge Density, $\mu C/m^3$	
17	3550B	380	13,400	>25,000
19	3551B	121	5,190	10,100
21	3552B	96	8,780	>20,100
23	3553B	634	13,400	>23,500
25	3554B	196	5,000	>7,690
27	3555B	139	2,260	>22,100
4	2926	168	14,600	>19,500
5	3055	120	12,900	>23,200
6	3119	148	12,000	>22,000
7	3166	116	12,200	>23,800
8	3219	426	16,200	>22,000
9	3084	104	12,400	>21,700
10/11	3475/3476	447	20,000	>15,600
12	3477	188	24,700	>17,100
13	3478	385	24,700	>18,900
14	3479	283	22,600	>17,100
15	3480	238	23,900	>14,640
30	3627A	126	7,110	>22,600
32	3633A	146	3,355	>17,385
35	3638A	157	5,490	>17,700
37	3639A	113	3,730	>20,700
39	3640A	128	12,400	>17,100

Table 11– Charging Tendency of Fuels Containing Stadis 450, but no Betz, on Type 10 and Type 1 Filter Media

NRL Sample No.	AF POSF No.	Conductivity, pS/m	Filter Medium	
			Type 10	Type 1
			Charge Density, $\mu C/m^3$	
16*	3550A*	103	1,570	>-12,200
18*	3551A*	106	3,710	>-9,880
22*	3553A*	562	9,390	>-9,150
24*	3554A*	152	6,280	-8,240
26*	3555A*	65.6	6,530	>-1,040
2B*	3428B*	55.4	5,020	>-1,415
31*	3627B*	67.3	738	>-1,190

* Plus 1 ppm Stadis 450

Table 12– Charging Tendency of Fuels Containing Betz and Stadis 450 on Type 10 and Type 1 Filter Media

NRL Sample No.	AF POSF No.	Conductivity, pS/m	Filter Medium	
			Type 10	Type 1
			Charge Density, $\mu C/m^3$	
17*	3550B*	536	12,200	>22,700
19*	3551B*	311	16,500	>24,400
21*	3552B*	409	15,500	>21,400
23*	3553B*	947	11,000	>21,000
25*	3554B	478	12,000	>22,600
27*	3555B	345	12,900	>23,800
28*	3116*	338	18,200	>23,800
28*	3116*	337	17,900	>23,100

* Plus 1 ppm Stadis 450

For fuels containing neither Betz nor Stadis, charging was generally higher on the Type 1 medium than on Type 10, but overall, was low on both media (Table 9).

The differences in the charging tendencies on the Type 10 and Type 1 filters is more obvious for fuels containing either Betz or Stadis 450, or both additives (Tables 10-12). Once again, the values for the Type 1 filter are reported as "greater than" since equilibrium was not reached at the end of the run. With the Betz additive (Table 10) and with the combination of Betz and Stadis (Table 12), charging was about twice as high on the Type 1 medium as on the Type 10 reference paper. Fuels containing Stadis 450 alone produced far less charging than fuels containing the Betz additive – see Table 11.

Failure to achieve equilibrium with the Type 1 filter was attributed to the greater density and thickness of this filter vs. the Type 10. The Type 1 filter actually consists of two layers: a solid layer and a fibrous layer. The charging currents obtained on Type 1 filter consisting of two layers are shown in Fig. 20. It is apparent from this figure that equilibrium was not reached at the end of the run when the two layers were used. So the filter was separated into a solid layer and a fibrous layer and the charging tendency test repeated. The results for the individual layers are given in Figs. 21 and 22. These curves indicate that the currents for the solid layer and the fibrous layer are approaching equilibrium at the end of the run. The sum of the currents for the two layers, namely -2.18×10^{-8} (solid layer) and -1.90×10^{-8} (fibrous layer), gives -4.08×10^{-8}, which, perhaps, is the equilibrium value of the Full Filter (Fig. 20). Again, the curve for the same fuel on Type 10 filter (Fig. 23) shows that equilibrium was achieved on that filter.

Charging of fuels containing Stadis 450 on the Type 1 filter was erratic (Table 11); some fuels clearly charged higher on the Type 1 filter than on the Type 10, (see Samples 16, 18 and 24 on Table 11) and some charged lower on Type 1, particularly Samples 26 and 28.

Fig. 20-Rising Filter Current Curves for Fuel Sample 21 Using Type 1 Filter (Two Layers)

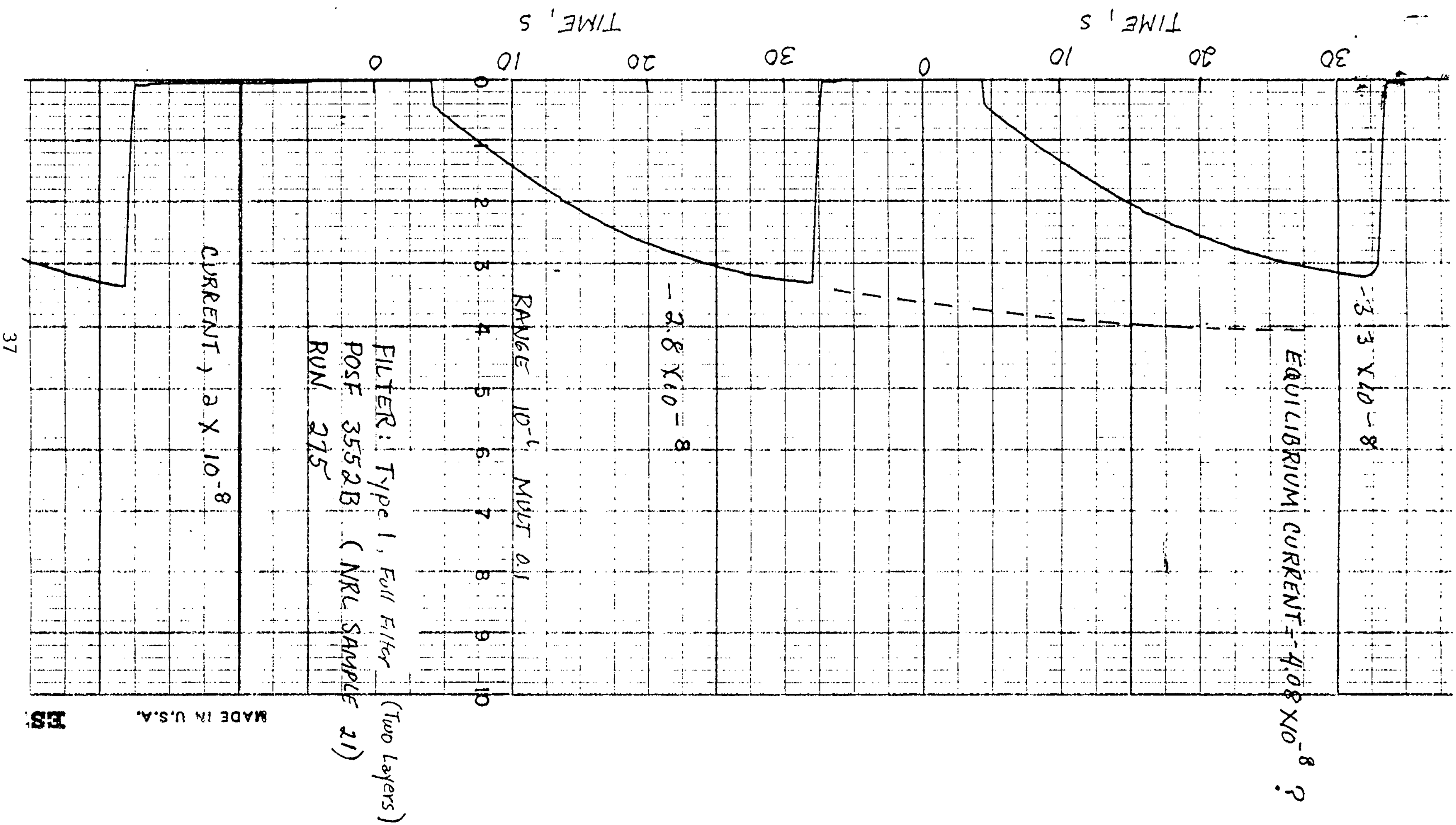


Fig. 21-Rising Filter Current Curves for Fuel Sample 21 Using Type 1 Filter (Solid Layer)

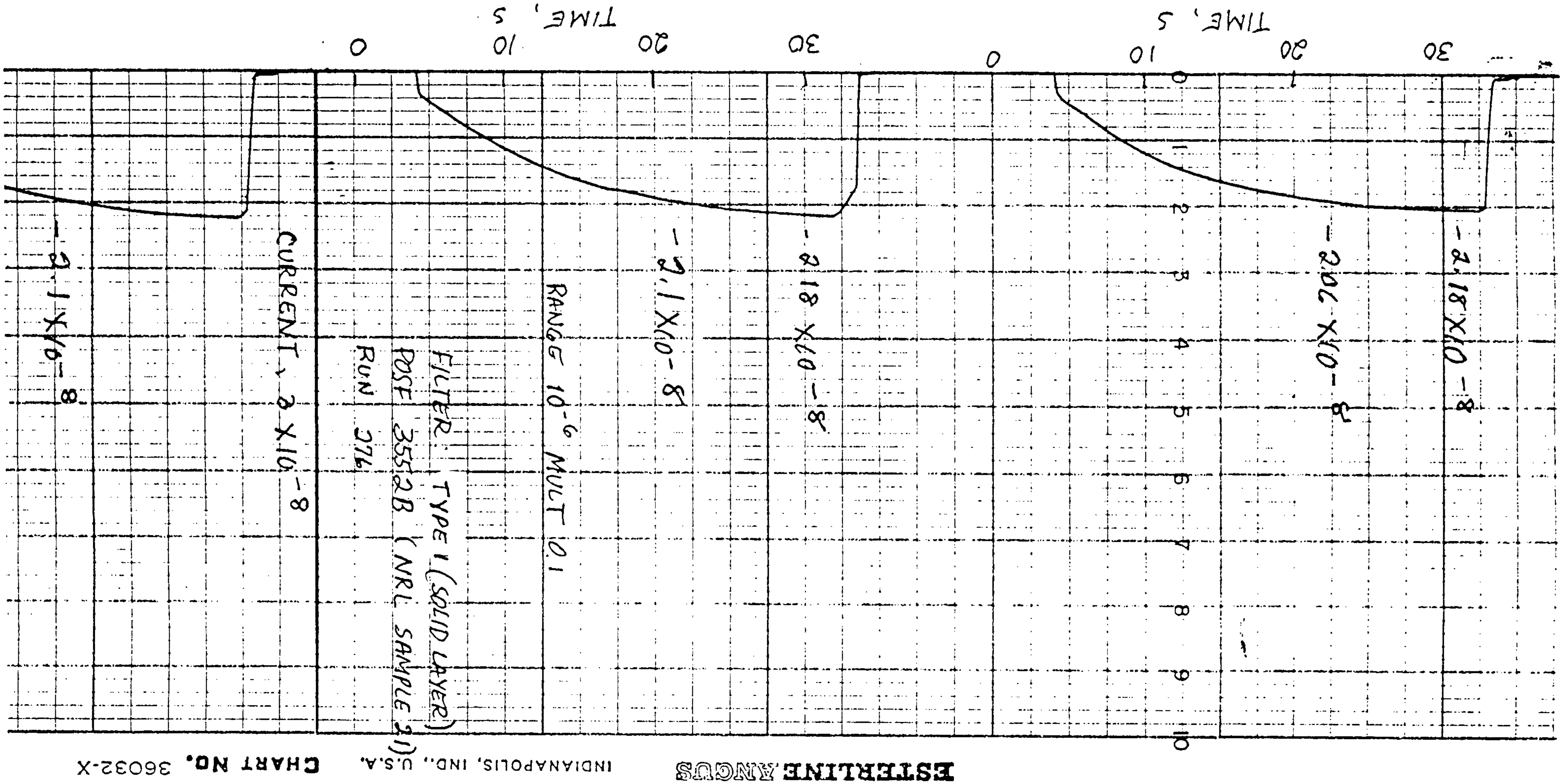
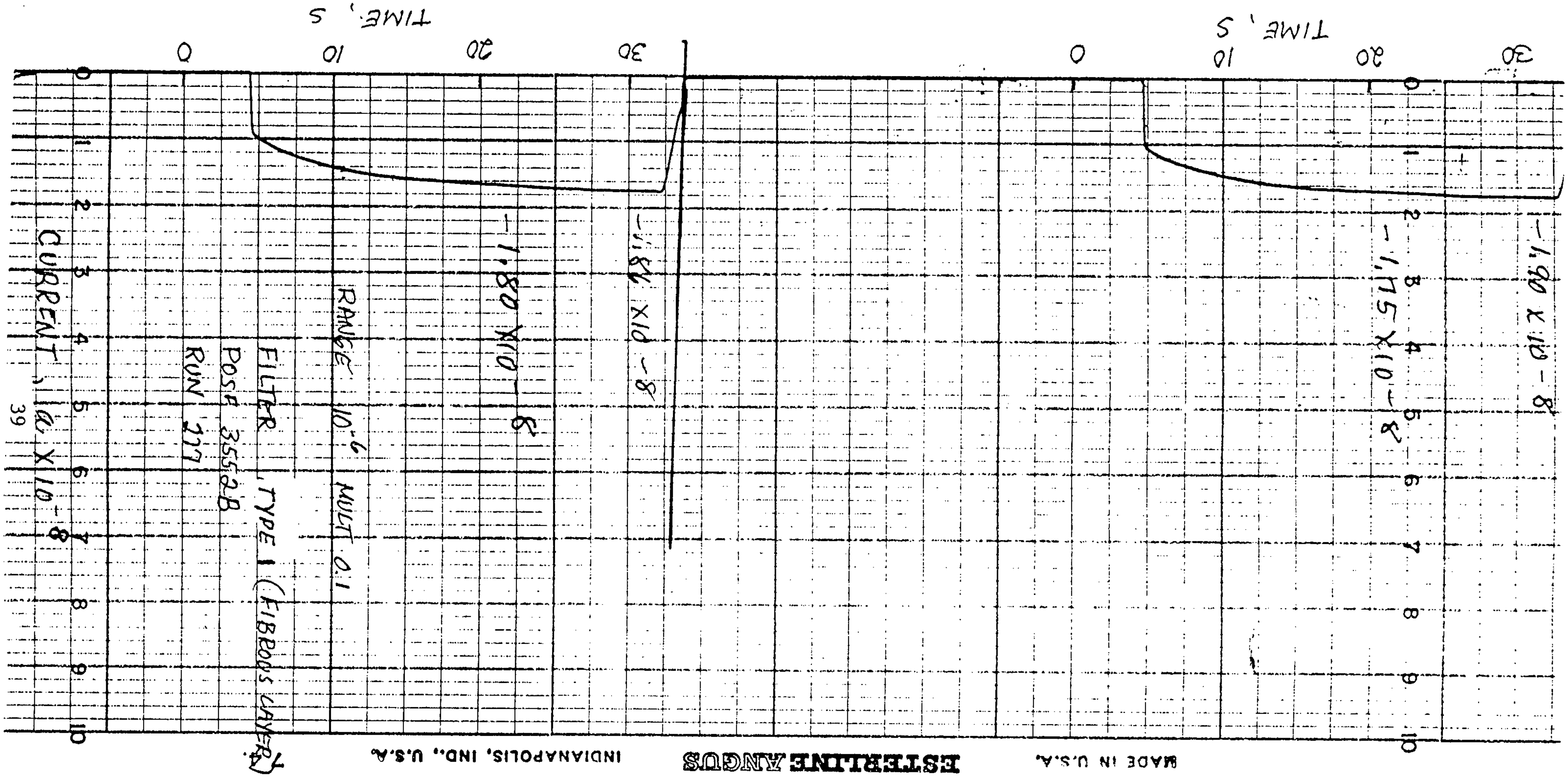


Fig. 22-Filter Current Curves for Fuel Sample 21 Using Type 1 Filter (Fibrous Layer)



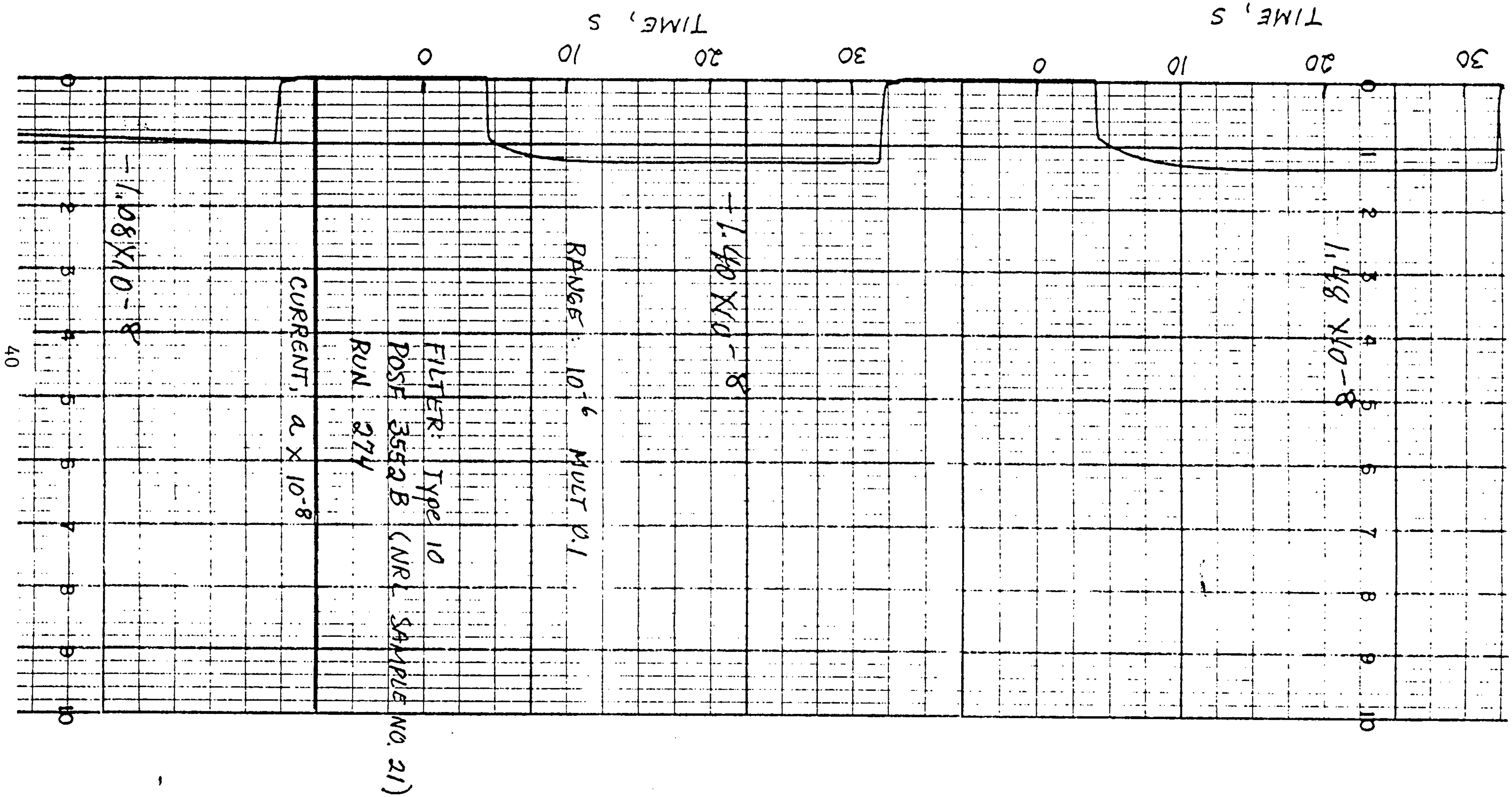


Fig. 23-Filter Current Curves for Fuel Sample 21 Using Type 10 Filter

According to the manufacturer, the Type 1 filter is an experimental material and is not used in any of their current filters.

Charging on Foam

A comparison was made of the charging tendency of fuels, with and without the Betz or Stadis 450 additives on both the non-conductive, blue foam (10) and on the newer conductive foams (11). The foams and their appropriate Military Specifications are listed in Table 13. The apparatus and procedure were the same as used in an earlier study of electrostatic charging of JP-4 fuel on polyurethane foams (5). The results of these tests as given in Table 14 clearly show that the Betz additive had little effect on charging on either the non-conductive or the conductive foams. Stadis 450, on the other hand, increased the charging tendency on both the non-conductive and conductive foams to approximately 300 $\mu C/m^3$, which is even higher than the maximum value of 184 $\mu C/m^3$ found earlier for JP-4 fuel containing the static dissipater additive ASA-3 on blue foam (5). High charging on the blue foam is considered to be a potential hazard since the foam is not conductive, and hence can retain a charge. On the other hand, high charging on the conductive foam by a high conductivity fuel would not be considered hazardous since both the fuel and the foam would dissipate the charge rapidly.

Table 13– Foams Used in Charging Tendency Tests

Manufacturer	Conductive Class	Color	Military Specification	Type
Non-Conductive Foam				
Foamex	N/A	Blue	MIL-B-83054 (10)	V (F.P.)*
Conductive Foams				
Crest	II	Charcoal grey	MIL-PRF-87260 (11)	III (F.P.)*
Foamex	I	Charcoal grey	MIL-PRF-87260 (11)	VI (F.P.)*
Foamex	II	Charcoal grey	MIL-PRF-87260 (11)	VII (F.P.)*

* F.P. = Fine Pore

Table 14 – Charging Tendency of Jet A Fuels on Reticulated Foam

NRL Sample No.	AF POSF No.	Conductivity, pS/m	Foamex Blue	Crest II	Foamex I	Foamex II
			Charge Density, $\mu C/m^3$			
A. Samples with No Additives						
43	3601A	0.30	-24	-24	-17	-66
45	3602A	0.41	-4	-8	0	-92
41	3593A	2.99	-32	-24	-24	-89
26	3555A	3.43	-29	-27	-3	N/A
B. Samples with Betz Additive						
44	3601B	109	-58	-10	6	-26
46	3602B	121	-23	-25	10	-30
42	3593B	121	-38	-13	-6	-29
C. Samples with Stadis 450						
43	3601A	256	40	40	7	N/A
45	3602A	59	-254	-281	-188	N/A
41	3593A	90	-305	-131	-65	-177
26	3555A	64	-191	-122	-189	-209

Effect of Storage on Conductivity and Charging Tendency

The effect of storage on conductivity and charging tendency was determined for:

1) Fuels containing neither Betz nor Stadis

2) Fuels containing Betz, but not Stadis

3) Fuels containing Stadis, but not Betz

4) Fuels containing both Betz and Stadis

All fuels contained CI and FSII. The samples were stored in epoxy-lined cans at room temperature for 5-14 months. The results of these determinations are shown in Tables 15-18.

The fuels that contained neither Betz nor Stadis (Table 15) had low initial conductivities and charging tendencies which remained fairly constant in storage for up to 14 months.

Table 15 – Effect of Storage on Conductivity and Charging Tendency of Fuels Containing Neither Betz nor Stadis 450 (Filter: Type 10 Paper)

NRL Sample No.	AF POSF No.	Conductivity, pS/m			Charge Density, $\mu C/m^3$			Storage Time (months)
		Initial	After Storage	Δ	Initial	Final	Δ	
2A	3428	0.22	0.81	+0.59	480	573	+93	14
18	3551A	2.86	6.54	+3.68	1,120	628	-492	5
20	3552A	0.31	0.18	-0.13	231	310	+79	5
24	3554A	9.44	7.62	+1.82	1,080	898	-182	5
26	3555A	3.43	3.43	0	1,890	1,330	-560	5

Table 16 – Effect of Storage on Conductivity and Charging Tendency of Fuels Containing the Betz Additive, but not Stadis (Filter: Type 10 Paper)

NRL Sample No.	AF POSF No.	Conductivity, pS/m			Charge Density, $\mu C/m^3$			Storage Time (months)
		Initial	After Storage	Δ	Initial	After Storage	Δ	
A. Samples in Normal Conductivity Range for Betz Additive								
4	2926	160	168	+8	11,500	14,600	+3,100	14
5	3055	110	120	+10	14,500	12,900	-1,600	14
6	3119	136	148	+12	14,400	12,000	-2,400	14
7	3116	110	116	+6	13,600	12,200	-1,600	14
9	3284	100	104	+4	15,100	12,400	-2,700	14
15	3480	228	238	+10	22,600	23,900	+1,300	11
19	3551B	121	125	+4	3,210	7,750	+4,540	5
21	3552B	90.5	94.5	+5	7,810	10,300	+2,490	5
25	3554B	186	195	+9	3,110	3,970	+860	5
27	3555B	132	142	+10	1,450	1,650	+200	5
B. High Conductivity Samples*								
8	3219	376	426	+50	17,700	16,200	-1,500	14
17	3550B	375	384	+9	12,000	14,000	+2,000	5
12	3477	280	188	-92	26,100	24,700	-1,400	5
13	3478	463	385	-78	26,000	24,700	-1,300	5
14	3479	468	283	-185	22,000	22,600	+600	5

* High conductivity indicates that samples may have contained Stadis 450 in addition to Betz additive, although they were not labeled as such

Table 17 – Effect of Storage on Conductivity and Charging Tendency of Fuels Containing Stadis, but not Betz Additive (Filter: Type 10 Paper)

NRL Sample No.	AF POSF No.	Conductivity, pS/m			Charge Density, μC/m^3			Storage Time (months)
		Initial	Final	Δ	Initial	Final	Δ	
A. Samples in Normal Conductivity Range for Jet A Fuels								
18*	3551A*	126	110	-16	1700	5370	3670	5
20*	3552A*	192	138	-54	5280	8174	2894	5
24*	3554A*	189	155	-34	<519**	6280	5761	5
26*	3555A*	108	71.2	-37	6100	7630	1530	5
B. Samples with Initially High Conductivities								
16*	3550A*	255	104	-151	1190	793	-397	5
22*	3553A*	611	458	-153	4180	11,650	7470	5

* Plus 1 ppm Stadis 450

** Charge Density could not be determined since charging current didn't reach equilibrium

Table 18 – Effect of Storage on Conductivity and Charging Tendency of Fuels Containing Betz and Stadis 450 (Filter: Type 10 Paper)

NRL Sample No.	AF POSF No.	Conductivity, pS/m			Charge Density, $\mu C/m^3$			Storage Time (months)
		Initial	After Storage	Δ	Initial	After Storage	Δ	
17*	3550B*	558	536	-22	9,760	12,200	+2,440	5
19*	3551B*	310	311	+1	16,410	16,470	+60	5
21*	3552B*	389	409	+20	16,600	15,500	-1,100	5
23*	3553B*3	921	947	+26	10,200	11,000	+800	5
25*	3554B*	451	478	+26	10,700	12,000	+1,300	5
27*	3555B*	355	345	-10	6,770*,**	12,900	+6,130	5
7*	3116*,**	338	337	-1	18,200	17,900	-300	---

* Plus 1 ppm Stadis 450

** Sample 3116 was stored for only 2 weeks

Most of the fuels containing the Betz additive that were in 'normal' conductivity range of 90-228 pS/m didn't change much in conductivity or charging tendency on storage for 5-14 months (Table 16). The exception was Sample 19 which showed a considerable increase in charging tendency, i.e., from 3210-7750 $\mu C/m^3$ after 5 months storage.

Some of the higher conductivity samples, which may have contained Stadis 450 as well as Betz, but were not labeled as such, showed a decrease in conductivity on storage (Samples 12, 13 and 14 on Table 16).

The conductivities of most samples containing Stadis, but not Betz, decreased in storage and their charging tendencies increased, except for Sample 16, which had a decrease in charging tendency (Table 17). Two samples, i.e. Samples 22 and 24, had increases of over 5000 $\mu C/m^3$. Although one sample exceeded 10,000 $\mu C/m^3$, in general, the charging tendencies for individual samples containing the Stadis 450 additive were lower than for the same samples containing the Betz additive. However, fuels varied widely in their responses to both additives.

The conductivities of all samples containing both Betz and Stadis did not change significantly in storage (Table 18). However, the charging tendencies of two samples, i.e., Samples 17 and 27, increased considerably in storage. Such changes, together with the observation the fuels vary widely in their responses to both additives, are indicative of the complex interactions that occur between the additives and chance impurities in fuels.

SUMMARY AND CONCLUSIONS

For fuels in the normal conductivity range of Jet A (0.1 – 10 pS/m), the Betz additive increased the conductivity of all but one sample to above 100 pS/m; for 15% of the samples, the conductivity was over 150 pS/m which is the lower specification limit for JP-8 fuels (7).

Stadis 450, at a concentration of 1 ppm, increased the conductivity of fuels not containing the Betz additive, on average, 138 pS/m: in fuels containing the Betz additive, the average increase was 252 pS/m.

The results of the charging tendency measurements for fuels on all of the filter media and reticulated foams tested are summarized in Table 19. As indicated in the table, Jet A fuels not containing the Betz or Stadis 450 additives exhibited low charging on all media, including the Type 10 reference filter.

Fuels containing the Betz additive gave low charging on all media except the Type 10 reference filter and a coalescer medium designated as Type 1. In some fuels, the charge densities for the Betz additive on the Type 10 filter equaled the highest levels attained in previous studies of additives, i.e., above 20,000 $\mu C/m^3$. Even higher charging was found on the Type 1 filter. However, such high charging is of little concern from the standpoint of electrostatic hazards under <u>most</u> circumstances since the conductivities of the fuels are so high, i.e. above 90 pS/m.

Table 19– Summary of Charging Tendency Data

Type of Medium	No Additive	With Betz	With Stadis 450
Coalescer, Excluding Type 1	Low	Low	High on fiberglass, felt, polyester and prefilter media
Type 1 Coalescer	Low	Very High*	Usually high, but not always
Separator, Excluding Type 10	Low	Low	Low
Type 10 Separator	Low	Very High*	Low
Monitor Cartridge	Low	Low	High on media paper and on superabsorbent and absorbent media
Foamex, Blue, Non-Conductive Foam	Low	Low	High**
Crest, Conductive Foam Class II	Low	Low	High**
Foamex, Conductive Foam Class I	Low	Low	High**
Foamex, Conductive Foam Class II	Low	Low	High**

* Usually >10,000 $\mu C/m^3$

** In the range of 100-300 $\mu C/m^3$, which is high charging on a foam

The high conductivity would permit most of the charge to dissipate in less than 1 second after it is generated. The possible exceptions where a hazard might exist despite the high conductivity of the fuel are: during the filling of an empty filter vessel or when the fuel flows over a low conductivity reticulated foam.

The charging tendencies of fuels containing the Betz additive varied widely. However, for a given fuel, the charging tendency increased steadily with increasing conductivity reaching a maximum in the range of 150-250 pS/m and then decreasing at higher conductivity levels. However, the high charging of fuels containing the Betz additive on the Type I experimental coalescer medium indicates the need for electrostatic testing of any new filter medium intended for use with JP-8 + 100 fuels.

Fuels containing Stadis 450 exhibited high charging on most coalescer media, particularly fiberglass and felt, and on the media paper and superabsorbent and absorbent media from the monitor cartridge. They also gave high charging on both the conductive and non-conductive foams, but not on the separator media or on the Type 10 reference filter. It should be emphasized that all of the filter media tested were designed for use with the Betz additive and may or may not be representative of the media being used with fuels containing Stadis 450 today.

Finally, in response to the original objective of this study, it was concluded that:

1) The Betz additive does not increase the electrical conductivity of all Jet A fuels above the current JP-8 specification minimum of 150 pS/m. Hence, the Betz additive does not obviate the need for a static dissipater additive in JP-8 fuels.

2) The Betz additive produced exceptionally high electrostatic charging on only two filter media, neither of which is currently being used with JP-8 fuels. Charging on all of the other 37 media tested was quite low for fuels containing the Betz additive.

REFERENCES

(1) Standard Test Method for Electrical Conductivity of Liquid Hydrocarbons by Precision Meter, Designation: D4308-95. American Society for Testing and Materials, Philadelphia, PA, February 15, 1995.

(2) Matulevicius, E., "Mini-Static Test Procedure," Exxon Research and Engineering Co., Linden, NJ, June 19, 1989.

(3) "A Survey of Electrical Conductivity and Charging Tendency Characteristics of Aircraft Turbine Fuels," CRC Report 478, Coordinating Research Council, Atlanta, GA, April, 1975.

(4) Leonard, J.T. and Bogardus, H.F., "Pro-Static Agents in Jet Fuels," Naval Research Laboratory Report 8021, August 16, 1976.

(5) Leonard, J.T. and Affens, W.A., "Electrostatic Charging of JP-4 Fuel on Polyurethane Foams", Naval Research Laboratory Report 8204, March 3, 1978.

(6) Standard Specification for Aviation Turbine Fuels, ASTM Designation D1655-96C, American Society for Testing and Materials, Philadelphia, PA.

(7) Military Specification: Turbine Fuel, Aviation, Kerosene Types, NATO F-34 (JP-8) and NATO F-45. MIL-T-83133D, Amendment 1, 19 September 1995.

(8) Leonard, J.T. and Carhart, H.W., "Effect of a Static Dissipater Additive on the Charging Tendency of Jet Fuels," Naval Research Laboratory Report 6952, November 12, 1969.

(9) Leonard, J.T. and Carhart, H.W., "Effect of Navy Special Fuel 0.1 on the Charging Tendency of Jet Fuel," Naval Research Laboratory Report 6953, November 20, 1969.

(10) Military Specification MIL-B-83054A (USAF), 15 August 1973, Baffle Material, Aircraft Fuel Tank.

(11) Performance Specification MIL-PRP-87260A (USASF), Foam Material, Explosion Suppression, Inherently Electrostatically Conductive, for Aircraft Fuel Tanks, 7 February 1992.